NAVY EXPERIMENTAL DIVING UNIT

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

3

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

IN REPLY REFER TO:

NAVSEA Task 86-30

NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 14-87

TEST AND EVALUATION OF MK 15 UBA BATTERY DURATION AND A MK 15 UBA OXYGEN ADDITION SOLENOID

CLARK G. PRESSWOOD
JOHN D. DUDINSKY
JOSH T. HERMANN

OCTOBER 1987

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Submitted:

C.G. PRESSWOOD
LT, USN
SPECWAR Projects Officer

J.D. DUDINSKY
Mechanical Engineer
NCSC (Code 3410)

J.T. HERMANN
LT, USN
SPECWAR Projects Officer

Reviewed:

R.T. MACHASICK
LCDR, USN
Operations/Projects Officer

D.J. SCHMITT
GM-13
Technical Support Dept. Head

H.J.C. SCHWARTZ
CDR, MC, USN
Senior Medical Officer

J.R. MIDDLETON
GM-14, Head, NCSC Diving Systems Branch

J.C. DEVLIN
CDR, USN
Executive Officer

Approved:

J.D.M. HAMILTON
CAPT, USN
Commanding Officer

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14-87	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Test and Evaluation of MK 15 UBA Battery Duration and a MK 15 UBA Oxygen Addition Solenoid		5. TYPE OF REPORT & PERIOD COVERED Test Report
		6. PERFORMING ORG. REPORT NUMBER 14-87
7. AUTHOR(s) Clark G. Presswood, LT, USN, J.D. Dudinsky, Mech Engineer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Navy Experimental Diving Unit Panama City, Florida 32407-5001		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NAVSEA Task 86-30 NEDU Test Plan 86-20
11. CONTROLLING OFFICE NAME AND ADDRESS Navy Experimental Diving Unit Panama City, Florida 32407-5001		12. REPORT DATE October 1987
		13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this Report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

load testing	oxygen consumption
milliamps	oxygen addition solenoid
MK 15 UBA	thermal response
manganese alkaline battery	volts
ohms	watts

20. ABSTRACT (continue on reverse side if necessary and identify by block number)

The Navy Experimental Diving Unit (NEDU) in conjunction with the Naval Coastal Systems Center (NCSC) conducted an evaluation of MK 15 MOD 0 UBA battery duration. Battery duration curves in various temperatures were developed, as was a new procedure for conducting predive testing of the MK 15 UBA battery with a load tester. A new MK 15 UBA battery assembled by Seatronics, Inc. was also evaluated, and found to provide improved duration over the currently used battery by a minimum of 10%. A new oxygen addition solenoid for use in the MK 15 UBA was evaluated and found to be a suitable spare part replacement item for the current solenoid.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Table of Contents

Page

Table of Contents.. ii
Abbreviations.. iv
Abstract... v

Section

I. INTRODUCTION.. 1

II. EQUIPMENT DESCRIPTION

A. MK 15 UBA... 1
B. MK 15 UBA Battery..................................... 3

III. TEST PROCEDURE

A. Phase I, Evaluation of Thermal Response of the Battery Assembly.................................... 4
B. Phase II, Evaluation of the Power Requirements of the MK 15 UBA.................................. 4
C. Phase III, Evaluation of the Effects of Temperature on Battery Duration at Various Oxygen Consumption Rates and Depths.................................. 8

IV. TEST RESULTS

A. Phase I... 8
B. Phase II.. 14
C. Phase III... 14

V. DISCUSSION

A. Battery Load Test Criteria............................ 14
B. MK 15 Battery Duration................................ 22
C. Predive Load Test Procedures and Dive Planning...... 22
D. Optimum MK 15 UBA Battery............................ 25
E. MK 15 UBA Solenoid.................................... 25

VI. CONCLUSIONS

A. Load Test... 25
B. Battery... 26
C. Solenoid.. 26
D. Battery Storage Life.................................. 26

APPENDIX A - Simplified Predive Load Test Procedures.......... A-1 thru A-2
APPENDIX B - Test Plan.. B-1 thru B-7

Page

FIGURES

Figure 1 - MK 15 UBA Functional Block Diagram................ 2
Figure 2 - Biosystems MK 15 UBA Battery..................... 5
Figure 3 - Biosystems and Seatronic MK 15 UBA Batteries...... 6
Figure 4 - Phase I, Battery Thermal Response Test Set Up..... 7
Figure 5 - Typical EDF Test Equipment Set-up for Unmanned UBA Performance Evaluation........................... 9
Figure 6 - Phase II, MK 15 UBA Power Requirements Test Set Up 10
Figure 7 - Oxygen Consumption Simulation Test................ 11
Figure 8 - Phase III, Effects of Temperature on Battery Duration Test Set Up............................. 12
Figure 9 - Battery Load Testing Criteria.................... 13
Figure 10 - Battery Thermal Response Time vs Temperature...... 15
Figure 11 - Solenoid Firing Rates as a Function of Oxygen Consumption.................................... 16
Figure 12 - Battery Life as a Function of Temperature, Depth, and Oxygen Consumption........................... 17
Figure 13 - Battery Discharge Curves at 75°F.................. 18
Figure 14 - Battery Discharge Curves at 55°F.................. 19
Figure 15 - Battery Discharge Curves at 40°F.................. 20
Figure 16 - Battery Discharge Curves at 30°F.................. 21
Figure 17 - Battery Load Test Voltage vs State of Discharge and Temperature........................ 23
Figure 18 - Load Test Voltage vs Time for Worst Case Battery Drain................................... 24

Abbreviations

ATA	atmosphere absolute
CNS	central nervous system
CO_2	carbon dioxide gas
°C	temperature degrees centigrade
°F	temperature degree Fahrenheit
EDF	NEDU Experimental Diving Facility
FSW	feet of seawater
HP	high pressure
ℓpm	liters per minute
NCSC	Naval Coastal Systems Center
NEDU	Navy Experimental Diving Unit
N_2	nitrogen gas
O_2	oxygen gas
PO_2	partial pressure of oxygen
UBA	underwater breathing apparatus
v	volts
W	watt
Ω	ohms

Abstract

The Navy Experimental Diving Unit (NEDU) in conjunction with the Naval Coastal Systems Center (NCSC) conducted an evaluation of MK 15 MOD 0 UBA battery duration. Battery duration curves in various temperatures were developed, as was a new procedure for conducting predive testing of the MK 15 UBA battery with a load tester. A new MK 15 UBA battery assembled by Seatronics, Inc. was also evaluated, and found to provide improved duration over the currently used battery by a minimum of 10%. A new oxygen addition solenoid for use in the MK 15 UBA was evaluated and found to be a suitable spare part replacement item for the current solenoid.

KEY WORDS:

load testing
milliamps
MK 15 UBA
manganese alkaline battery
ohms
oxygen consumption
oxygen addition solenoid
thermal response
volts
watts
NAVSEA Task 86-30
NEDU Test Plan 86-20

I. INTRODUCTION. Per NAVSEA Task 86-30, NEDU and NCSC (Code 3410) conducted an evaluation of MK 15 MOD 0 UBA battery duration and a new oxygen addition solenoid. This task was divided into three major areas:

A. The currently used MK 15 UBA battery manufactured by Biosystems, Inc., Rockfall, CT, and a new battery manufactured by Seatronics, Inc., Hatboro, PA, were tested to determine average battery discharge curves under various conditions.

B. Testing was conducted on a new oxygen addition solenoid provided by Rexnord, Inc. which is advertised to have reduced power requirements.

C. The requirements for pre-dive testing of the MK 15 UBA battery with a load tester were evaluated.

The goal of battery testing was to determine battery life expectancy in various water temperatures. This required that various oxygen consumption rates also be evaluated. The oxygen consumption rate determines the rate of firing of the oxygen addition solenoid, which imposes a significant power drain on the battery. Use of a new oxygen addition solenoid which draws less power provides a potential for increased battery life.

In order to ensure that batteries contain sufficient power prior to a dive, an adequate procedure for testing the battery prior to use is required. Current battery test procedures include testing under a no-load condition, which may not provide an accurate indication of a battery's true state. A better measurement of battery capacity remaining is acquired by testing the battery under a load.

It was therefore the purpose of testing to provide battery duration guidelines; to furnish recommendations on improving the duration of the MK 15 UBA power supply by evaluating the use of an optimum battery, reduced power solenoid, and improved battery test procedures.

II. EQUIPMENT DESCRIPTION

A. MK 15 UBA. The MK 15 MOD 0 UBA is a closed circuit mixed gas rebreather which utilizes a nitrogen-oxygen breathing medium to a maximum depth of 150 FSW, and maintains a constant 0.7 ATA partial pressure of oxygen. Figure 1 provides a functional block diagram of the MK 15 UBA. Maximum efficiency of breathing medium is accomplished by removing carbon dioxide produced by metabolic action of the body and adding oxygen to the inspired gas as required. Movement of recirculating gas through the circuit is normally accomplished by the natural inhalation and exhalation action of the divers lungs. Check valves in the mouthpiece ensure a one-way flow of gas through the circuit.

Carbon Dioxide is removed from the breathing circuit in a watertight canister of carbon dioxide absorbent material located in the back pack of the UBA. A breathing bag (counter lung) or diaphragm is used to provide necessary

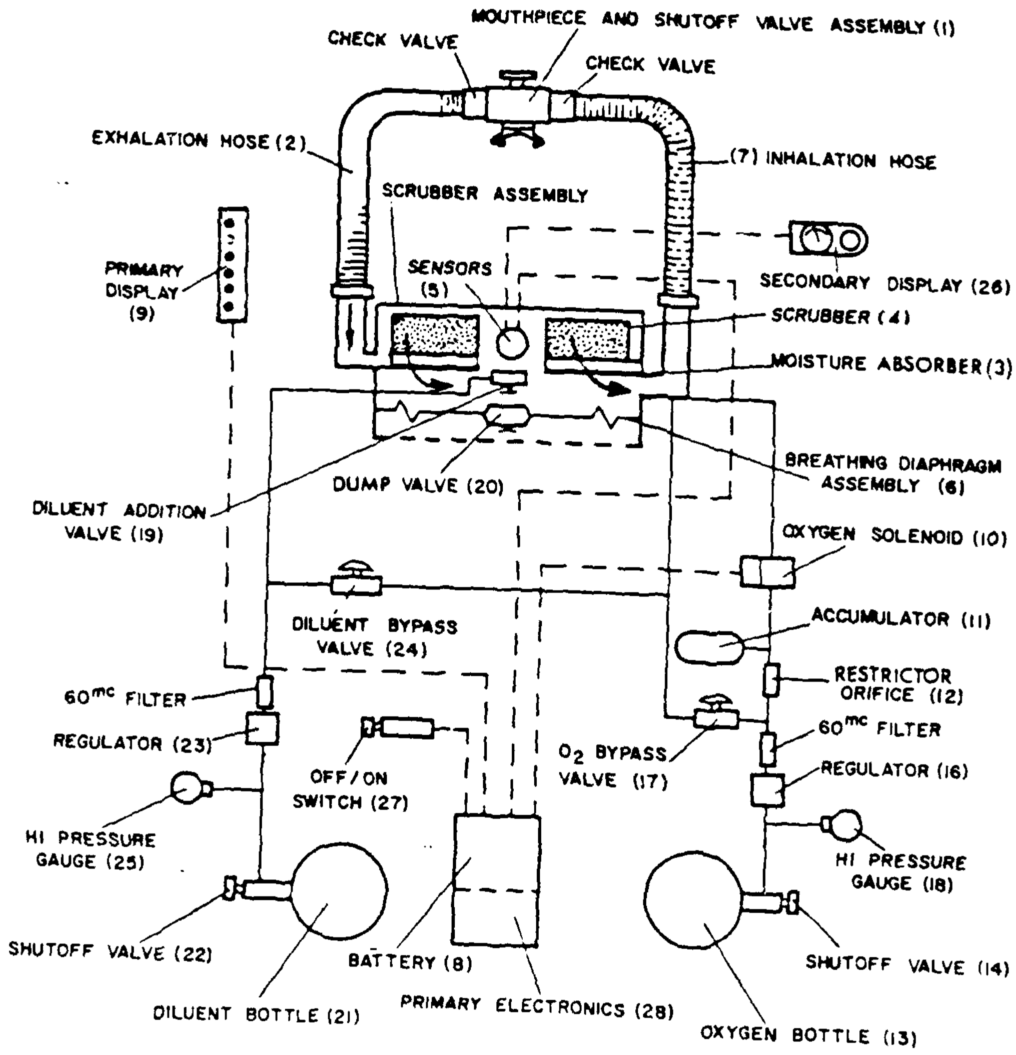


Figure 1. MK 15 UBA Functional Block Diagram

compliance in the circuit. In order to avoid the hazards of hypoxia and Central Nervous System (CNS) oxygen toxicity, accurate metering of oxygen addition into the breathing circuit is essential to control the partial pressure of oxygen (PO_2) in the breathing medium within narrow limits for safe operation.

The MK 15 UBA utilizes a direct control method of maintaining oxygen concentration in the system. Oxygen concentration is measured by sensors which generate an electrical output through galvanic reaction of oxygen coming in contact with a sensing electrode. The sensors monitor the PO_2 and send signals to the electronics module and the secondary display. The electronics module amplifies or limits signal strength, compares actual PO_2 value with set point value, and controls the oxygen addition solenoid valve. An actual PO_2 less than the set point (normally 0.70 ± 0.10 ATA) automatically activates the solenoid to admit oxygen to the recirculation system. Oxygen addition continues until the PO_2 in the breathing loop is brought back to the predetermined set point, after which the automatic control system maintains the valve in the shut position.

Two displays provide the diver with continuous information on PO_2, battery condition, and oxygen sensor function. The primary display consists of five illuminated, sequential letters and numbers to indicate normal, high, and low oxygen levels. An alarm light is also provided to indicate a malfunctioning oxygen sensor, high or low oxygen level, electronics failure, or limited remaining battery life.

The secondary display is an analog meter which indicates both sensor output and battery voltage. Individual sensor output is obtained by manually selecting output from sensor one, two, or three. A noteworthy aspect of secondary display functioning is that battery power is not required for secondary display operation. The galvanic reaction of gaseous oxygen coming in contact with the oxygen sensors provides an electrical output independent of the MK 15 battery which allows oxygen level monitoring on the secondary display. If battery depletion or MK 15 electronic failure occurs, it is possible for the diver to continue the dive in the manual mode by monitoring the oxygen level on the secondary display and adding oxygen via the manual bypass valve to maintain the required PO_2. It is therefore essential that divers monitor displays frequently to determine proper functioning of the battery and electronics, so that ample warning is provided if switching to the manual mode is required.

B. MK 15 UBA Battery. The MK 15 battery pack consists of 18 individual size AA battery cells spot welded in series. A previously used MK 15 battery provided by Rexnord Inc. consisted of 18 AA manganese alkaline Duracell batteries contained in a metal case and potted in epoxy. The current battery is procured at a cheaper price from Biosystems, Inc. and consists of 18 Eveready cells. In the Biosystems, Inc. battery, all cells and spot welds are then coated on each cell end with an epoxy-like substance and contained in a cardboard case partially covered with shrink-wrap plastic.

A new battery provided by Seatronics, Inc. was also evaluated. This battery is very similar in design to the original Rexnord battery except that new Duracell AA "cram-cell" batteries are used, which are advertised to provide longer duration and increased shelf life. Figure 2 provides an illustration of the Biosystems MK 15 battery. Figure 3 provides an illustration of the current Biosystems and new Seatronics MK 15 UBA batteries.

III. <u>TEST PROCEDURE</u>. A determination of MK 15 battery life as a function of water temperature and diver work rate required three phases of evaluation.

A. <u>Phase I, Evaluation of Thermal Response of the Battery Assembly</u>. The battery case, potting, and individual battery cell wrapping provides insulative properties. Assigning battery life data as a function of water temperature requires an understanding of the time required for internal battery temperature to equalize with external ambient temperature. If batteries are removed from a freezer prior to use, temperature changes may occur within the battery prior to use. Additionally, if batteries are maintained at a given warm temperature prior to immersion in cold water, a thermal response time occurs before the internal battery temperature chills to ambient water temperature. UBA cache in a dry environment between repetitive dives may also have an effect on internal battery temperature changes.

In order to determine battery thermal response time, a MK 15 battery installed in a MK 15 UBA electronics module was instrumented with a thermocouple which was inserted through the electronics module housing into the center of the battery. Figure 4 provides an illustration of the test set up as well as information on the thermocouple and monitoring equipment.

The electronics module was stored overnight in various air temperatures ranging from -20°F to 70°F. It was then immersed in seawater at temperatures ranging from 30°F to 80°F. Thermal response of the unit was then recorded in a temperature verses time format. A mathematical model was then developed taking into account the thermal characteristics of the battery and case. The result of the mathematical model differed from actual test data by as much as 25%, therefore the theoretical approach was abandoned. This test was repeated with an uninsulated battery (not installed in electronics module) exposing the battery to various air temperatures.

B. <u>Phase II, Evaluation of the Power Requirements of the MK 15 UBA</u>. As discussed in Section II of this report, the oxygen sensors and secondary display do not require an external power supply for operation, however two main power consuming activities are present within the MK 15 UBA. The primary power consuming activity is the electronics module and primary display, which has a relatively steady state power requirement whenever the unit is turned on. The oxygen addition solenoid is another power consumer. Power requirements are directly related to solenoid rate of firing which is contingent upon diver work rate (oxygen consumption), and to a lesser extent by depth.

MK 15 UBA batteries were wired with current shunts in series with the positive (red) and negative (black) leads of the battery in order to measure

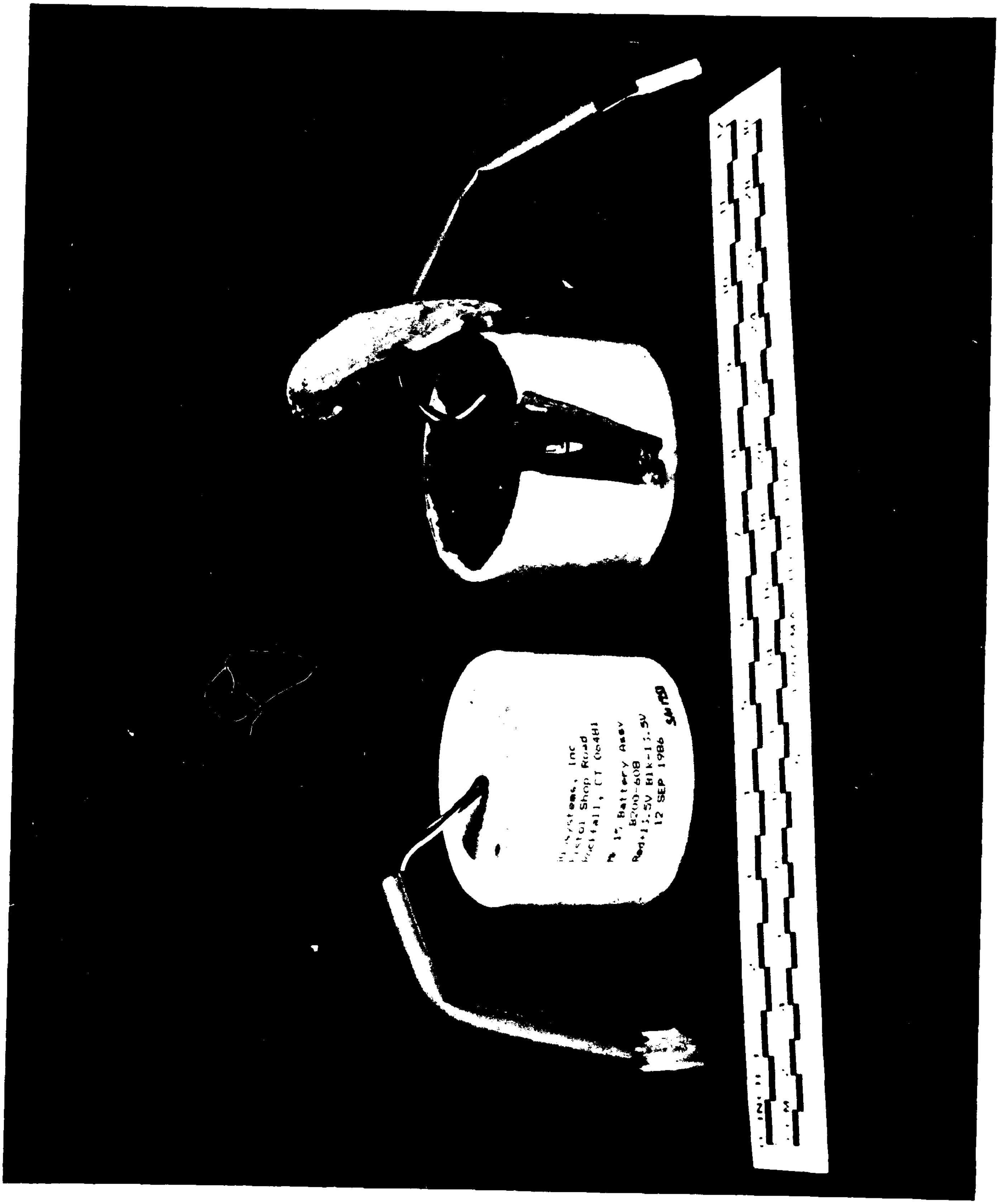


Figure 2. Biosystems MK 15 UBA Battery

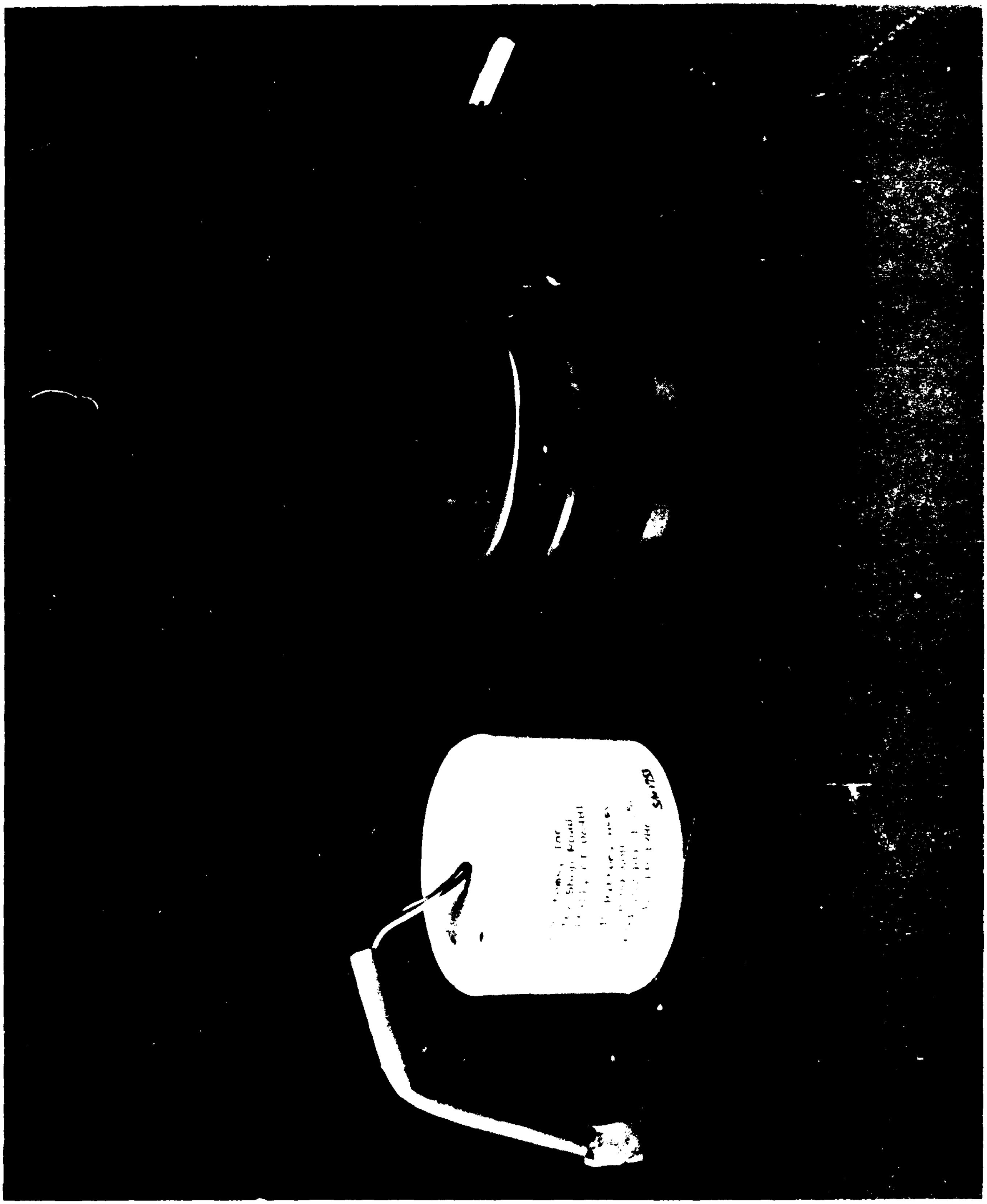


Figure 3. Biosystems and Sentronics MK 15 UBA Battery

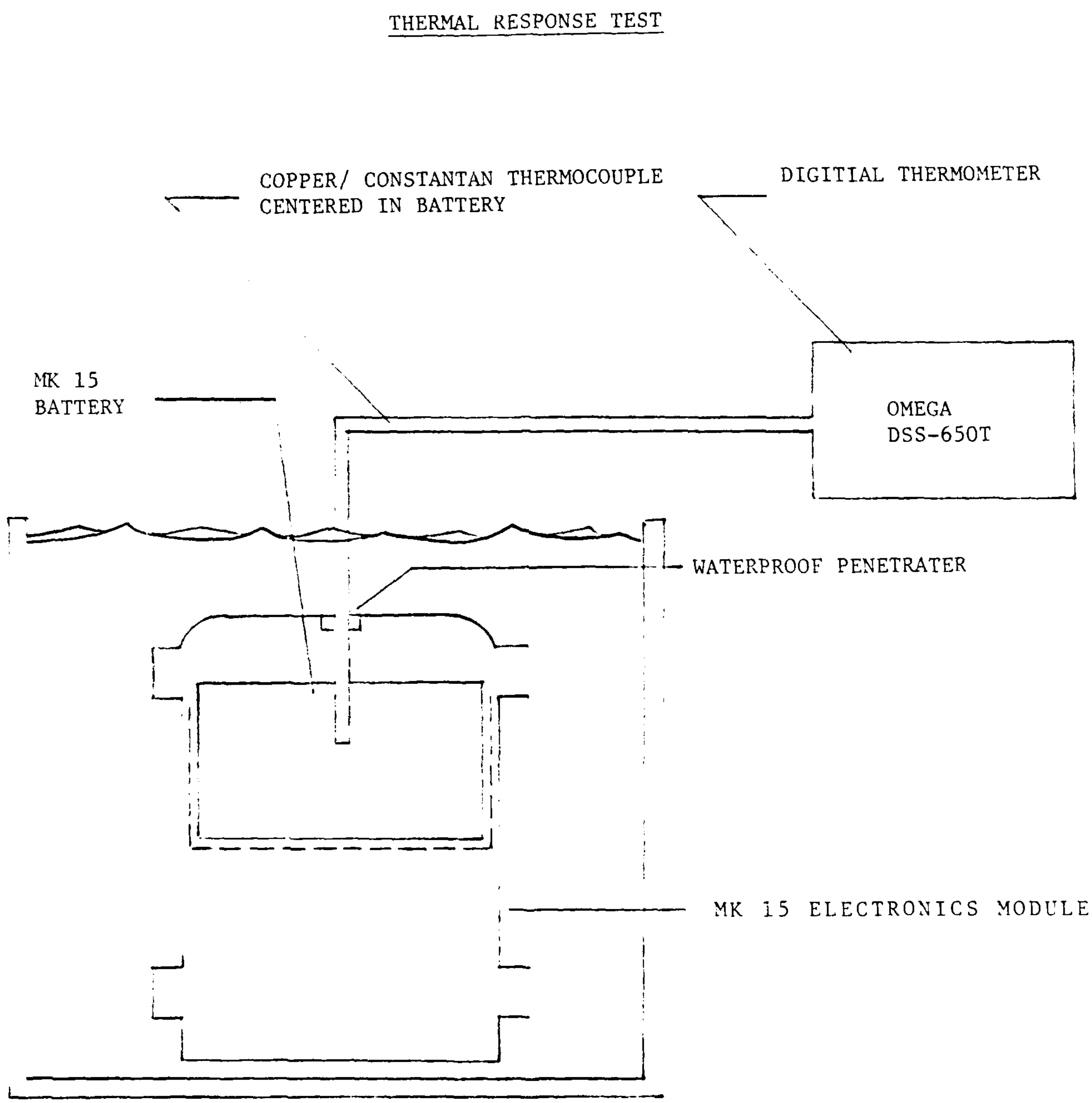


Figure 4. Phase I, Battery Thermal Response Test Set Up

the current flowing through the battery. An oscilliscope was used to measure the battery current (voltage change across the resistor). Battery current was observed and recorded for both the solenoid firing and steady state MK 15 UBA operation. Both the currently used 6.0 watt and new 4.5 watt solenoid provided by Rexnord were evaluated.

Once the electrical current requirements of the electronics assembly and the oxygen addition solenoid were recorded, the solenoid firing characteristics of the UBA were determined in the Experimental Diving Facility's (EDF) Bravo Chamber. A diagram of typical EDF test equipment set up for standardized unmanned UBA breathing performance and CO_2 absorbent canister duration evaluation is provided in Figure 5.

Precision resistors were monitored using a chart recorder as illustrated in Figure 6. Oxygen consumption rates of 1.0, 1.5, 2.0, and 2.5 ℓpm were simulated with the oxygen consumption simulator as illustrated in Figure 7. Testing was conducted at depths of 33, 66, and 99 FSW. The number of solenoid firings and the time between firing sequences was measured by reading the strip chart recorder output.

C. Phase III, Evaluation of the Effects of Temperature on Battery Duration at Various Oxygen Consumption Rates and Depths. Once the evaluation of MK 15 UBA power requirements was completed at the various oxygen consumption rates and depths (various solenoid firing rates), a determination of the effects of temperature on battery life, at the various oxygen consumption rates was made. This allowed development of a means of testing batteries to determine percentage of life remaining.

During Phase II testing, strip charts were generated which show the overall pattern of solenoid firing for each oxygen consumption rate and depth combination. Using this information, a test apparatus was designed which artificially drains a battery without actually requiring that gas be run through a MK 15 UBA at depth. A schematic of the test set-up is provided in Figure 8. This test consisted of a steady current drawn by a resistor in parallel with an actual MK 15 UBA oxygen addition solenoid which is switched in and out of the circuit using a computer driven controller.

With this test set-up, battery life was determined at different temperatures by discharging a battery at thermal equilibrium with the test freezer. Load testing was conducted periodically to check for minimum battery voltage. Figure 9 provides the load testing criteria. Test temperatures were 30°, 40°, 50°, 60°, and 70°F.

IV. TEST RESULTS

A. Phase I. The MK 15 battery assembly was found to reach complete equilibrium with ambient water temperature within three to four hours. The thermal response of the battery is exponential. Within one hour, the battery temperature will change to within 30% of the original temperature differential between the internal battery temperature and external water temperature.

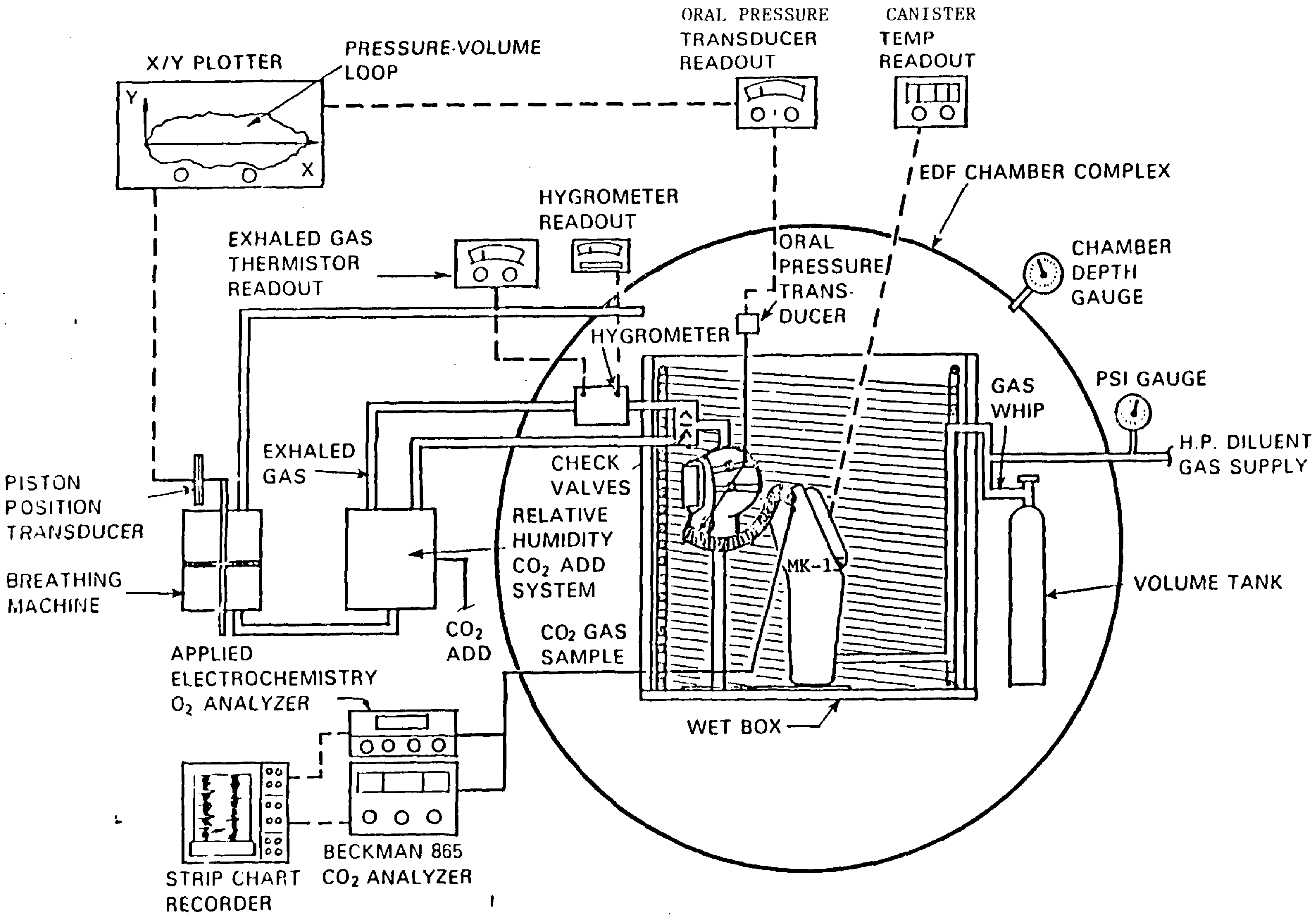
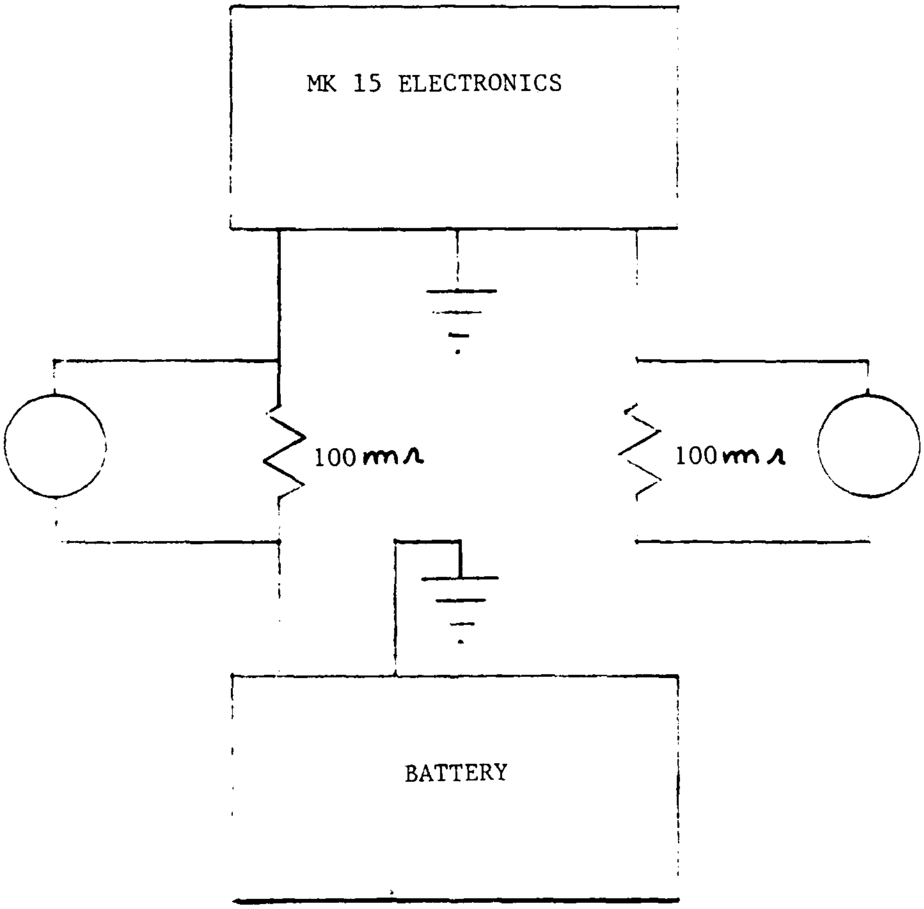


Figure 5. Typical EDF Test Equipment Set Up for Unmanned UBA Performance Evaluation

CURRENT SHUNT SCHEMATIC



$V = iR$

$i = V/0.1\Omega$

Figure 6. Phase II, MK 15 UBA Power Requirements Test Set Up

MK 15 BATTERY TEST SCHEMATIC

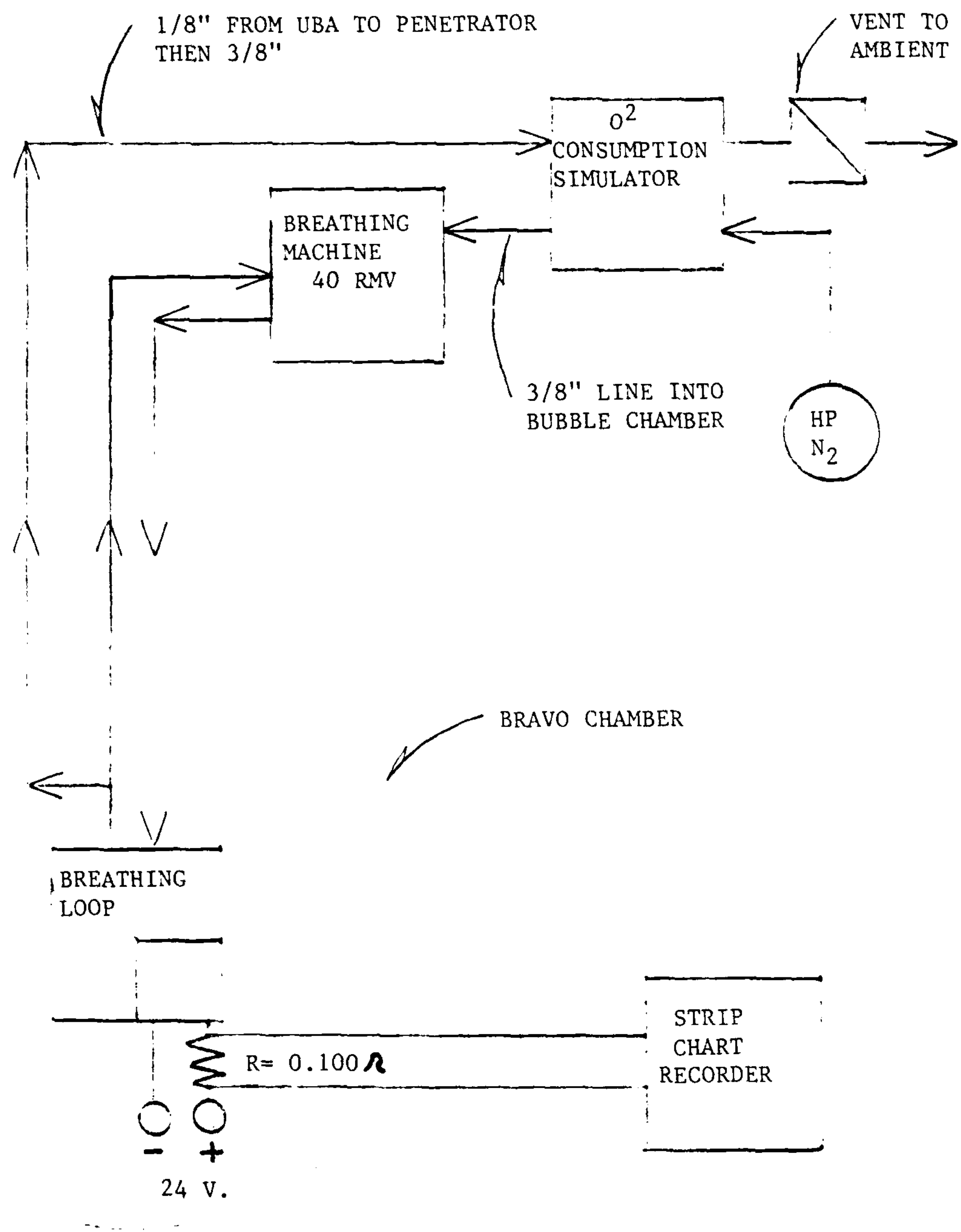


Figure 7. Oxygen Consumption Simulation Test

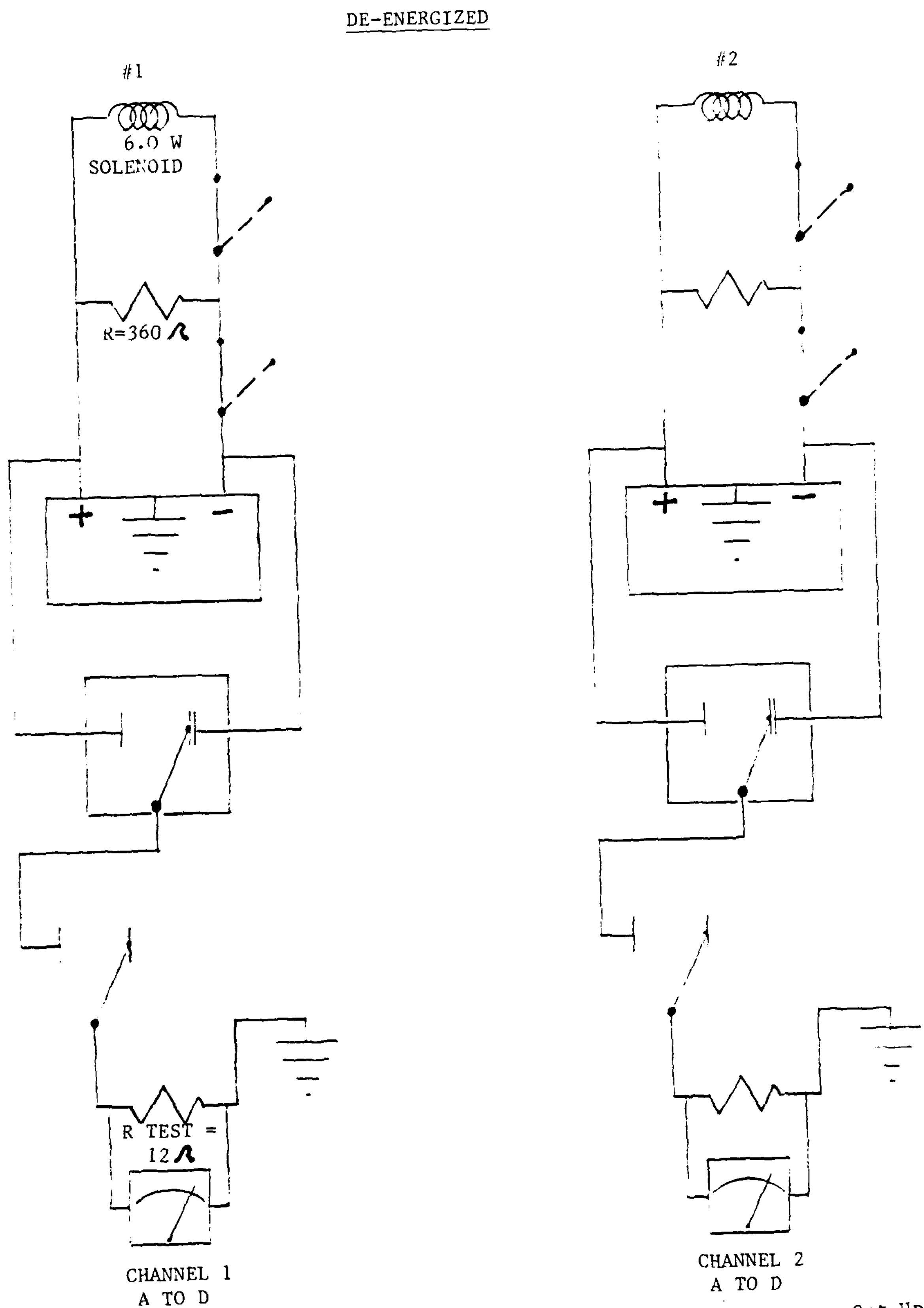


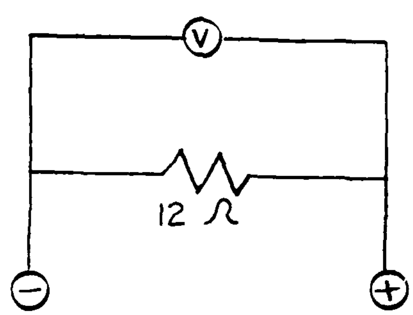
Figure 8. Phase III, Effects of Temperature on Battery Duration Test Set Up

FIGURE 9

BATTERY LOAD TESTING CRITERIA

The battery is taken out of the circuit every 0.5 hours and load tested using a 12Ω resistance. A lower limit for loaded voltage was taken to be 8.2v at 70°F. This limit was established by Duracell Battery Corp after considering the actual current requirements of the MK 15 and also the internal impedence characteristics of manganese dioxide alkaline batteries. The loaded voltage is taken at the end of 1 second (after loading) as recommended by Duracell.

LOAD TESTER SCHEMATIC



Within two hours the battery temperature will have dropped to within 10% of the original temperature differences. This remaining difference between battery and water temperature at the two hour interval is considered inconsequential from the standpoint of battery operation. After two hours, the battery should be considered as having equilibrated with the ambient water temperature. Figure 10 provides a graph of battery thermal response times when batteries at a given air temperature are exposed to a different water temperature.

In addition to the test discussed above, an uninsulated MK 15 battery (not contained within the electronics module) was exposed to varying air temperatures. The thermal response of an uninsulated battery exposed to varying air temperatures was found to be quite similar to the thermal response of the MK 15 electronics assembly exposed to varying water temperatures.

B. Phase II. Various MK 15 UBAs were found to draw from between 60 and 76 milliamps for basic electronic circuit operation. 68 milliamps was used as the basis for testing. In addition to this steady state load, the standard 6.0 watt oxygen addition solenoid draws 250 milliamps. The new 4.5 watt solenoid provided by Rexnord, Inc. draws 190 milliamps. The solenoid load is intermittent, with a 0.7 second wide step occurring every 3.7 seconds during the firing phase. The firing phase occurs at various intervals contingent upon oxygen consumption, and has a certain length. Solenoid firing rates as a function of oxygen consumption are outlined in Figure 11.

Further testing established that 12.5 volts is the minimum battery voltage necessary to operate the 6.0 watt solenoid. In this report, all voltages are presented in terms of average half voltage of the 18 cell MK 15 battery assembly. Therefore the minimum solenoid voltage requirement is 6.25 volts.

C. Phase III. During this phase of testing the batteries were placed under simulated load conditions. The loads provided are those which would be required by the MK 15 UBA at various oxygen consumption rates and depths. It was found that depth has little significant effect on battery life, although shallow depths will cause slightly more power drain than deeper depths. Discharge curves are therefore provided only for 33 FSW in Figures 12, 13, 14, 15, and 16. These figures provide battery load testing performance versus time at different temperatures. The data provided in these figures is based upon test results using the Seatronics battery and a 6.0 watt solenoid.

V. DISCUSSION

A. Battery Load Test Criteria. A method of rating the state of capacity remaining of the MK 15 Battery at anytime in its life span had to be developed in order to determine the actual lower limit of battery voltage and therefore duration times during the testing discussed in this report. This test method involves a load test procedure which will also apply to pre-dive battery testing. Testing a battery under proper load provides the only true indication of the actual internal status of the battery.

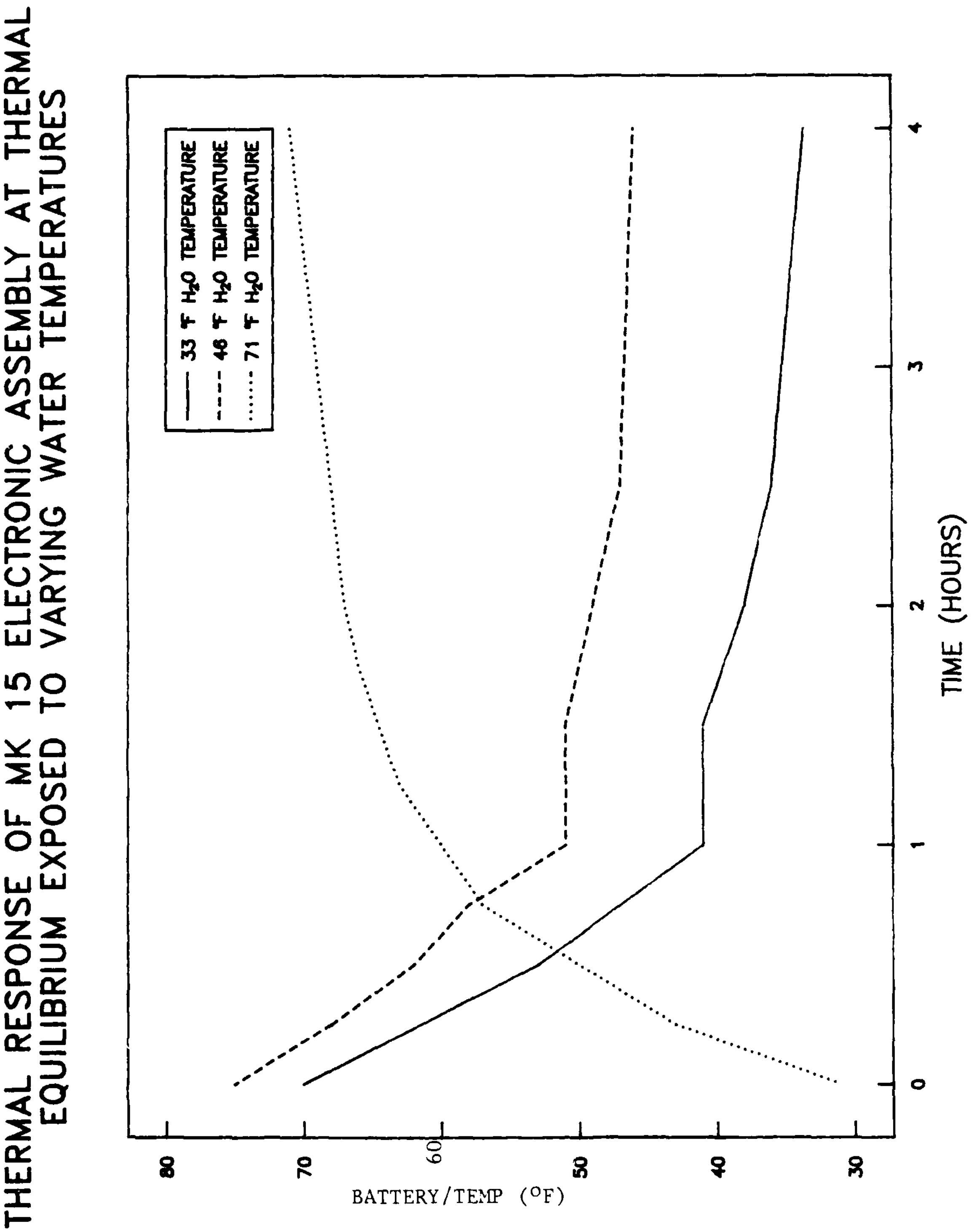
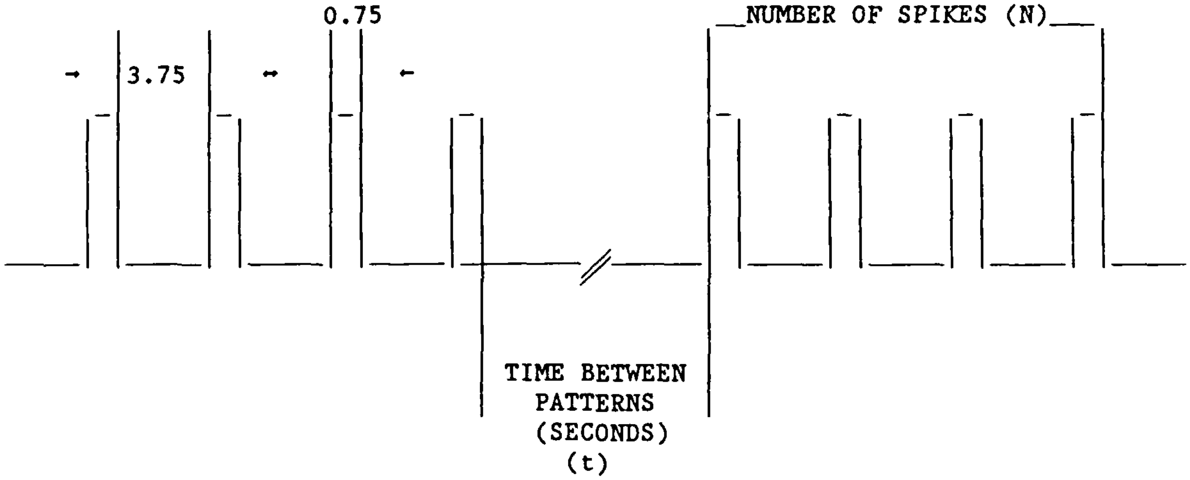


Figure 10. Thermal Response of MK 15 Electronic Assembly at Thermal Equilibrium Exposed to Varying Water Temperatures

TYPICAL FIRING PATTERNS FOR

OXYGEN ADDITION SOLENOID



PHASE II RESULTS

4.5W REXNORD (t/N)

Depth (FSW)	1.0 LPM	1.5 LPM	2.0 LPM	2.5 LPM
33	170/11	72/11	64/14	______
66	120/9	82/11	64/15	47/21
99	112/8	86/12	63/15	50/22

6.0 REXNORD (t/N)

Depth (FSW)	1.0 LPM	1.5 LPM	2.0 LPM	2.5 LPM
33	139/8	79/9	59/11	46/14
66	110/7	76/9	50/10	42/13
99	94/5	77/7	56/8	51/15

Figure 11. Solenoid Firing Rates as a Function of Oxygen Consumption

Figure 12. LOAD TEST VOLTAGE VS. TIME 75 DEG. F.

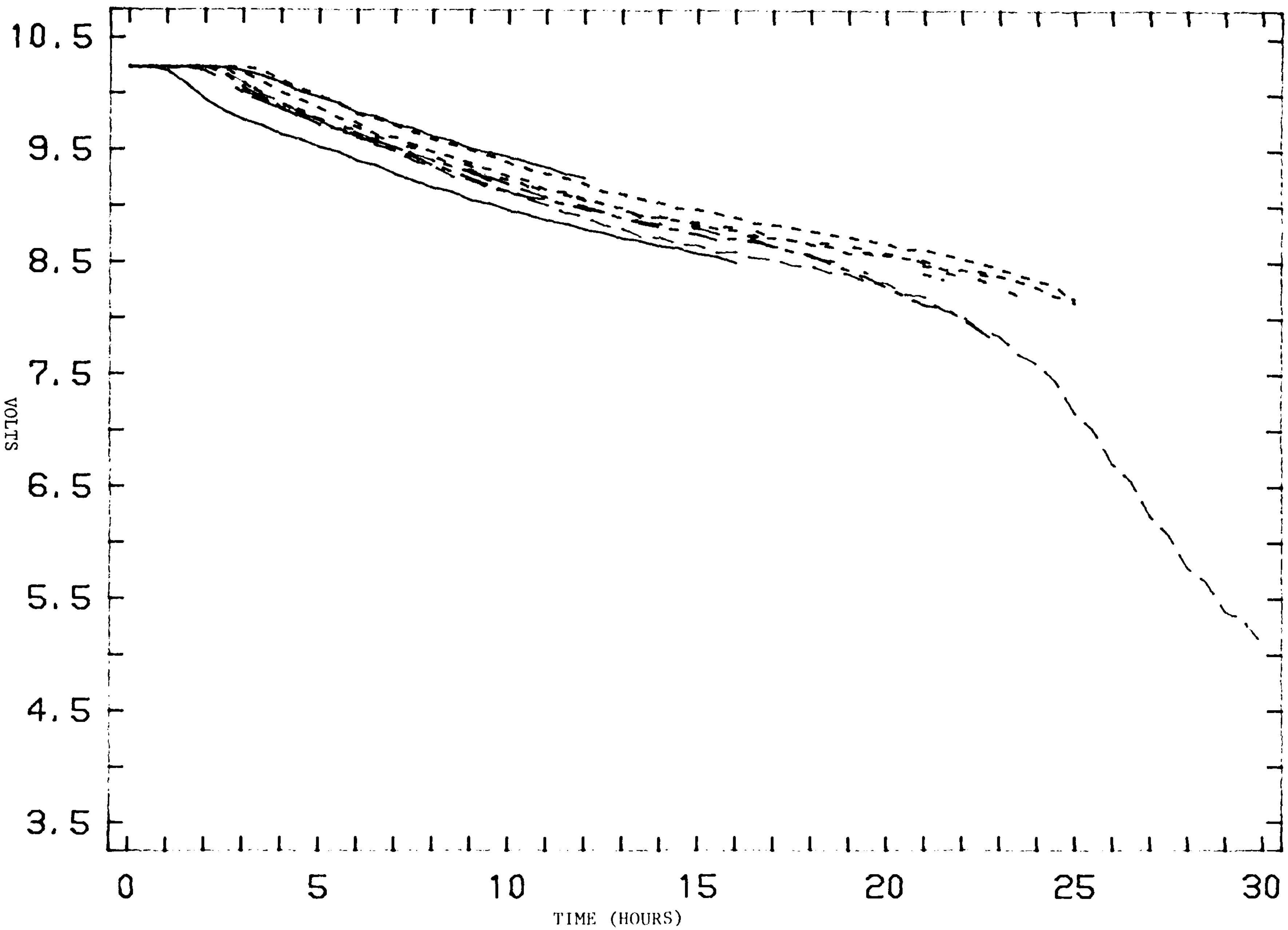


Figure 13. LOAD TEST VOLTAGE VS. TIME 55 DEG. F.

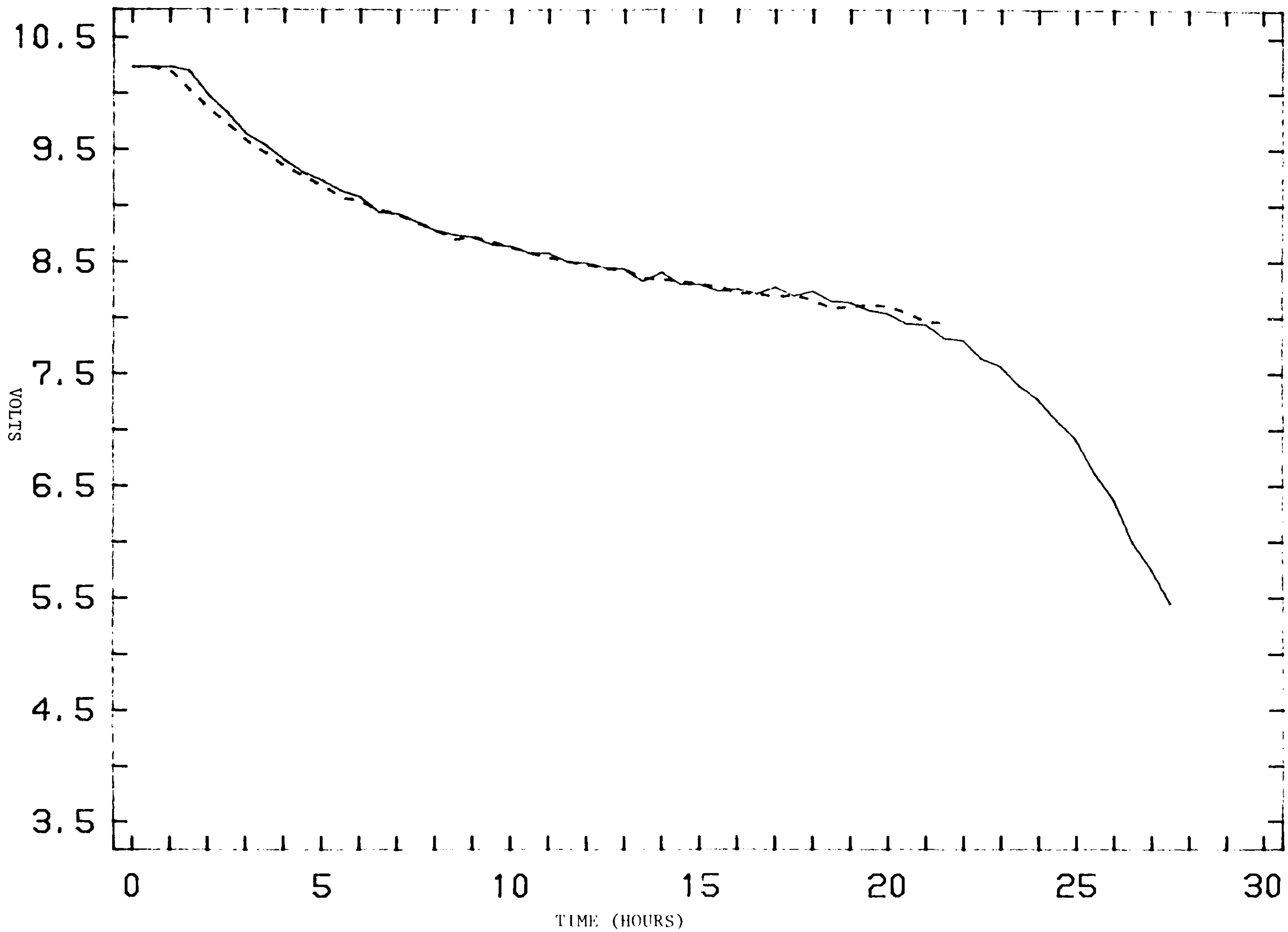


Figure 14. LOAD TEST VOLTAGE VS. TIME 50 DEG. F.

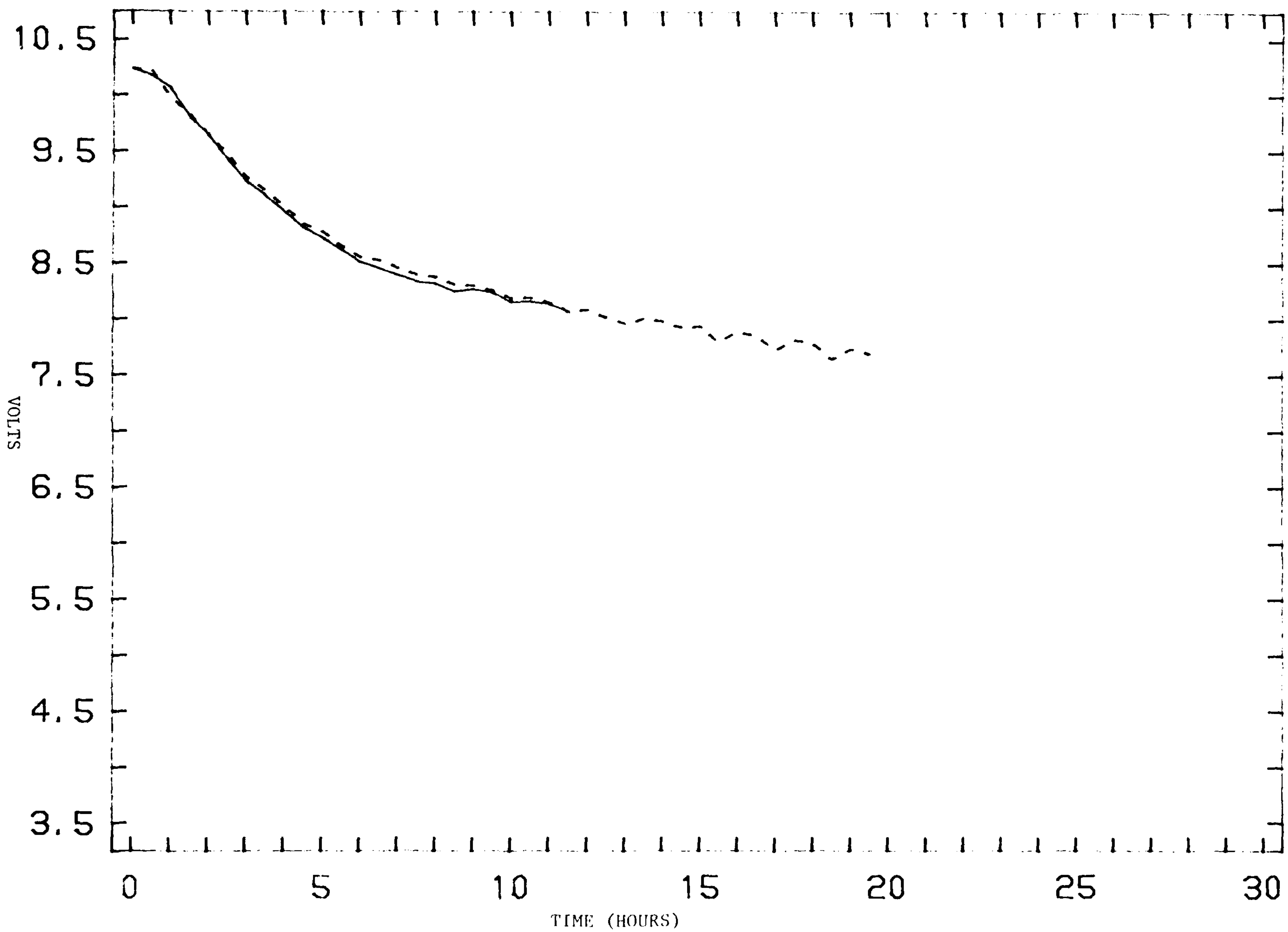


Figure 15. LOAD TEST VOLTAGE VS. TIME 40 DEG. F.

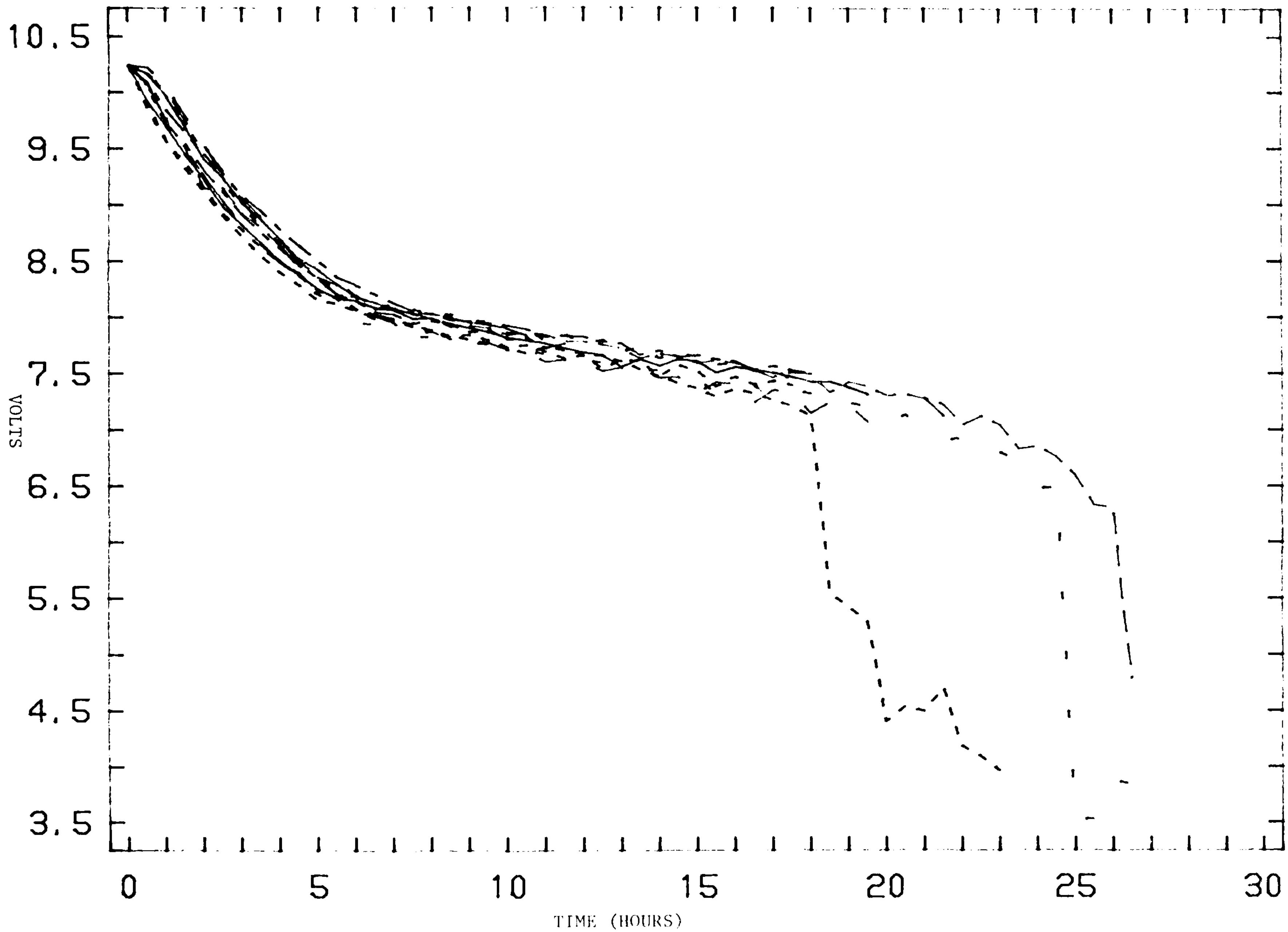
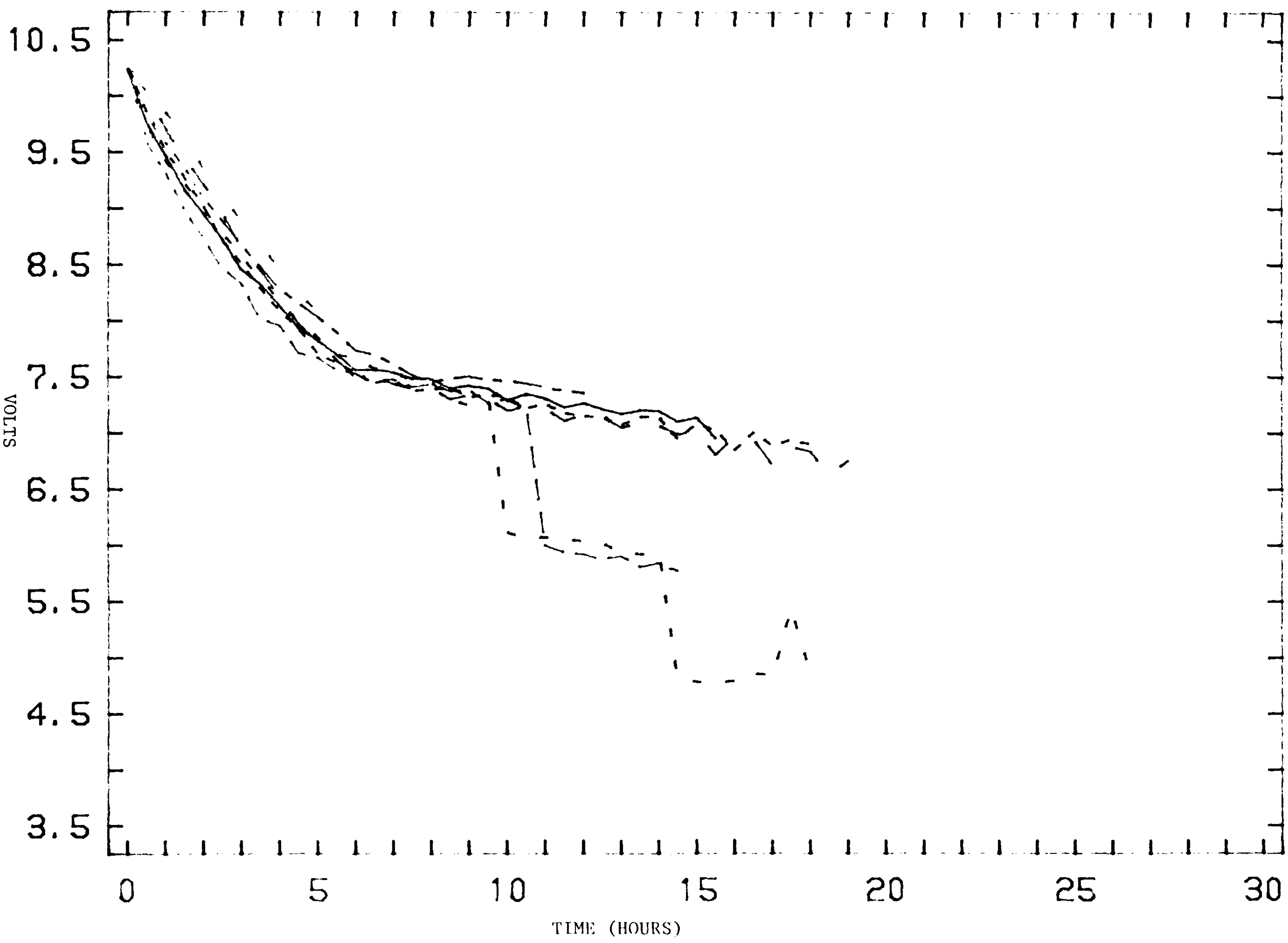


Figure 16. LOAD TEST VOLTAGE VS. TIME 30 DEG. F.



Discussions with Duracell, Inc., Bethel, CT, established proper load test criteria. Duracell recommended that the battery be loaded with a 12 ohm resistance for one second, and that the lower limit of battery voltage be 8.2 volts at room temperature (75°F). Voltages below 8.2 volts indicate termination of useful battery life.

During the testing procedure, it was found that battery voltage varied directly with temperature. This prompted an investigation into load tested voltage verses temperature for batteries of a known state of discharge. (The batteries were not under a power drain during these tests.) This data is provided in Figure 17. These limits are presented as a function of load testing temperature. Load testing temperature is defined as internal battery temperature, rather than ambient temperature.

Upon analyzing the data in Figure 17, it was decided to offset the recommended minimum voltage, 8.2 volts. The linear relationship of the average discharged batteries shows that battery voltage decreases .3 volts per 10°F drop in temperature. This offset must be added to the battery voltage in order to adjust for the difference in battery voltage caused by the difference between storage temperature and usage temperature. Figure 18 gives the temperature/voltages offset to be used when determining the batteries corrected voltage at the anticipated dive temperature.

B. MK 15 Battery Duration. Evaluation of the data provided in Figure 12 shows a large variation in battery life, even under identical test conditions. For example, a battery discharged at a rate corresponding to an oxygen consumption of 1.5 ℓpm at 33 FSW and 30°F yielded battery duration times of between 8.5 and 13 hours. This data scatter was observed even though all batteries tested were relatively new (purchased within six months prior to testing) and were ordered directly from the manufacturer. This scatter is most likely caused by shelf life discharge because all battery discharge curves were identical in shape. It was therefore decided to use the average of the curves minus one standard deviation calculated at the 8.2 volt recommended termination voltage. This method provides for 84% confidence in predicting the useful battery life remaining. Battery shelf life will be discussed later. Figures 19 through 23 are load test voltage vs. time curves adjusted one standard deviation.

Useful remaining battery life can be determined from Figures 19 through 23 using the initial temperature, voltage, temperature/voltage offset, and the water temperature of the anticipated dive. This process will be discussed in

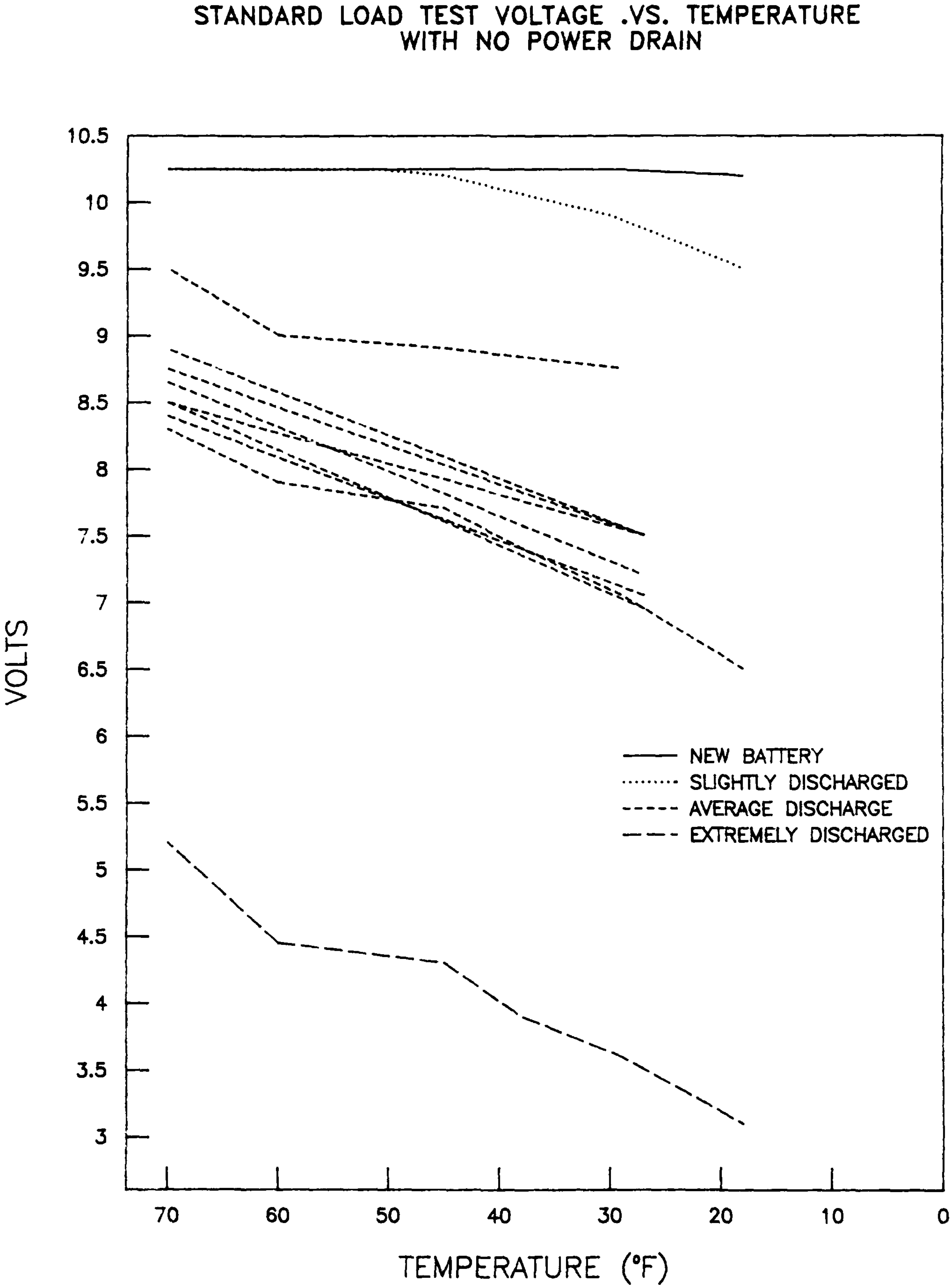


Figure 17. Battery Load Test Voltage vs State of Discharge and Temperature

TEMPERATURE/VOLTAGE OFFSET TABLE

Battery Storage Temperature	Water Temperature				
	30	40	50	60	70
30	0	.3	.6	.9	1.2
40	-.3	0	.3	.6	.9
50	-.6	-.3	0	.3	.6
60	-.9	-.6	-.3	0	.3
70	-1.2	-.9	-.6	-.3	0

Figure 18. Temperature Voltage Offset Calculated from Figure 17 for Average Discharged Batteries

Figure 19. LOAD TEST VOLTAGE VS. TIME 75 DEG. F.

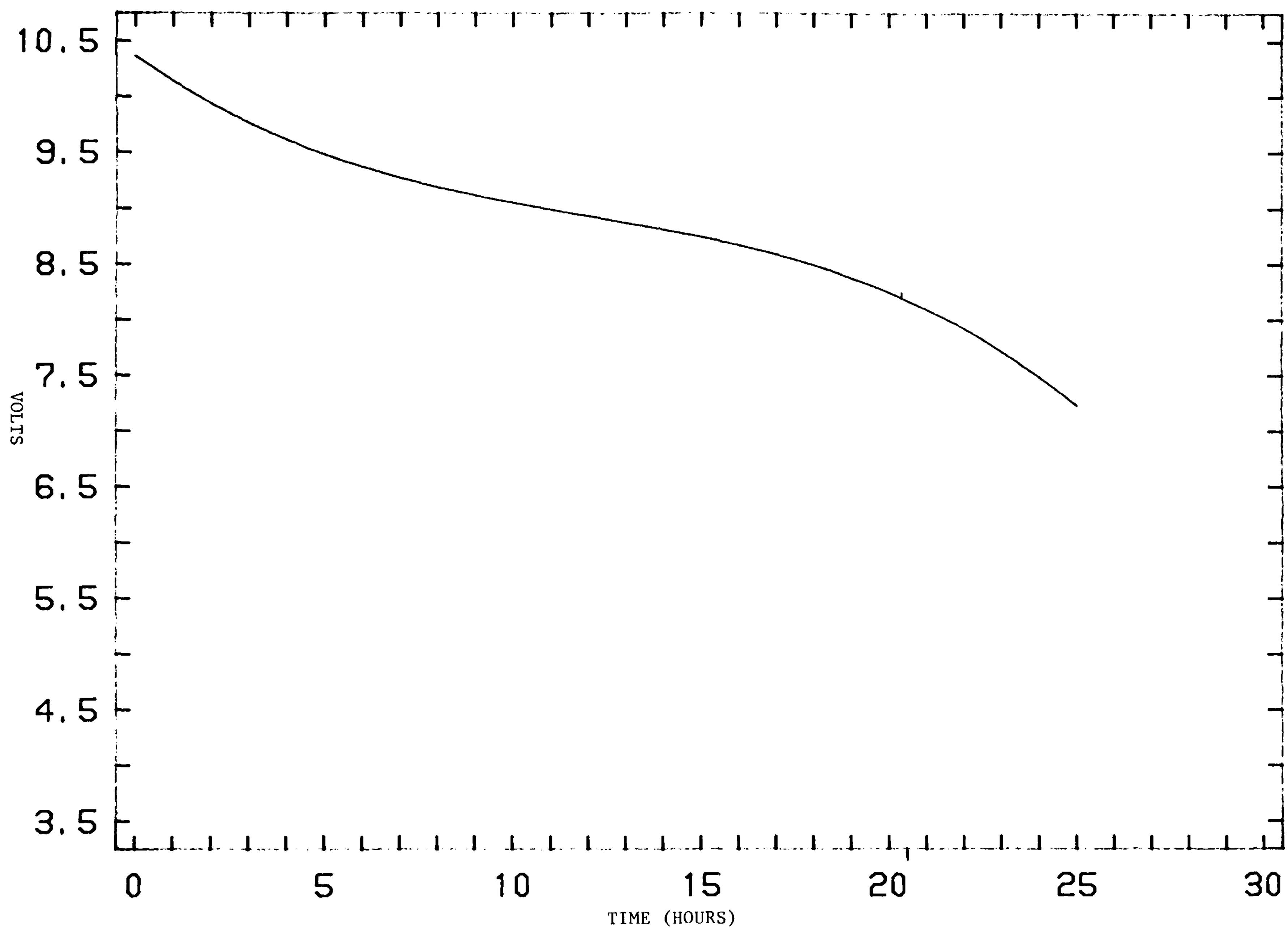


Figure 20. LOAD TEST VOLTAGE VS. TIME 55 DEG. F.

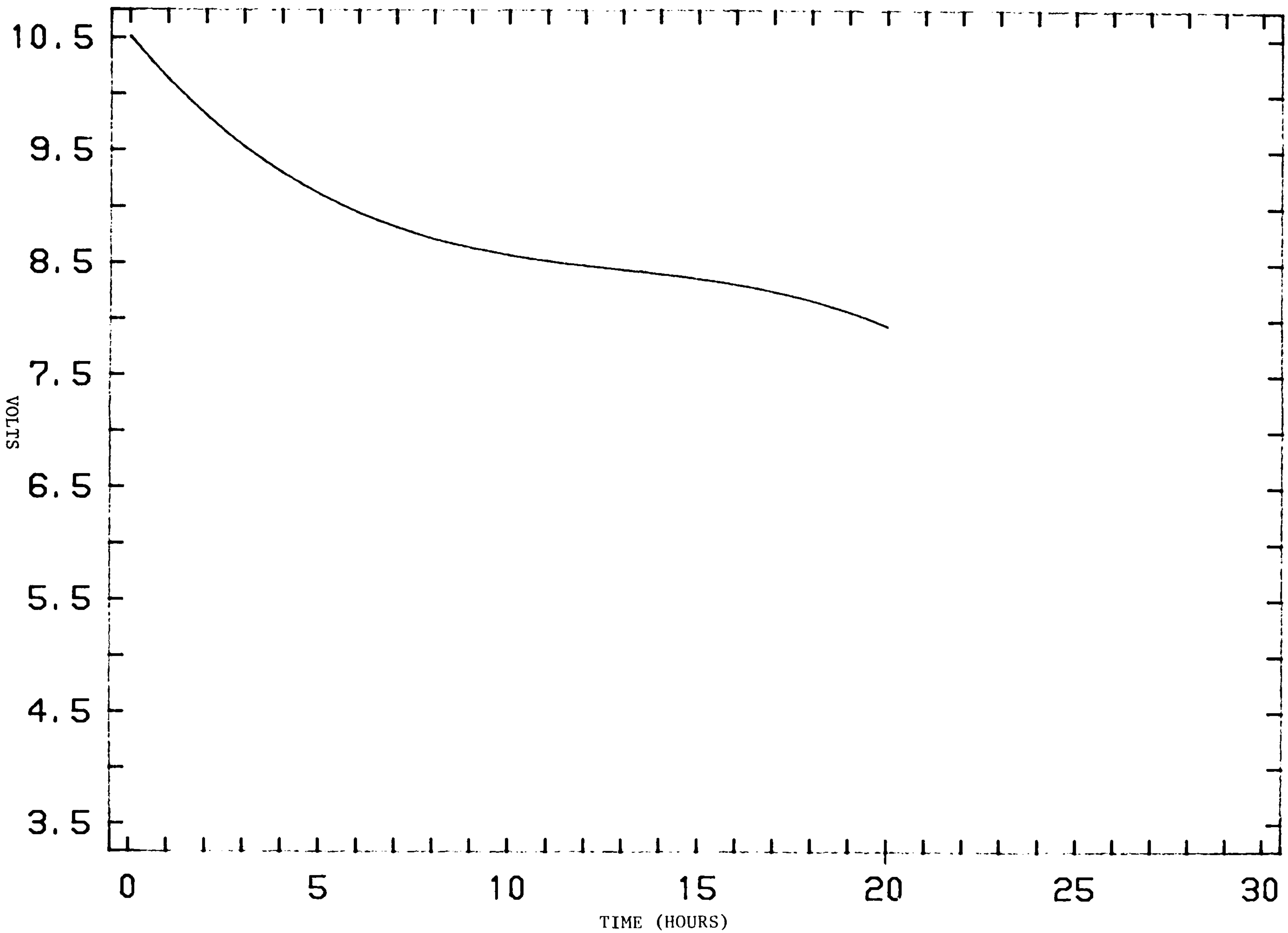


Figure 21. LOAD TEST VOLTAGE VS. TIME 50 DEG. F.

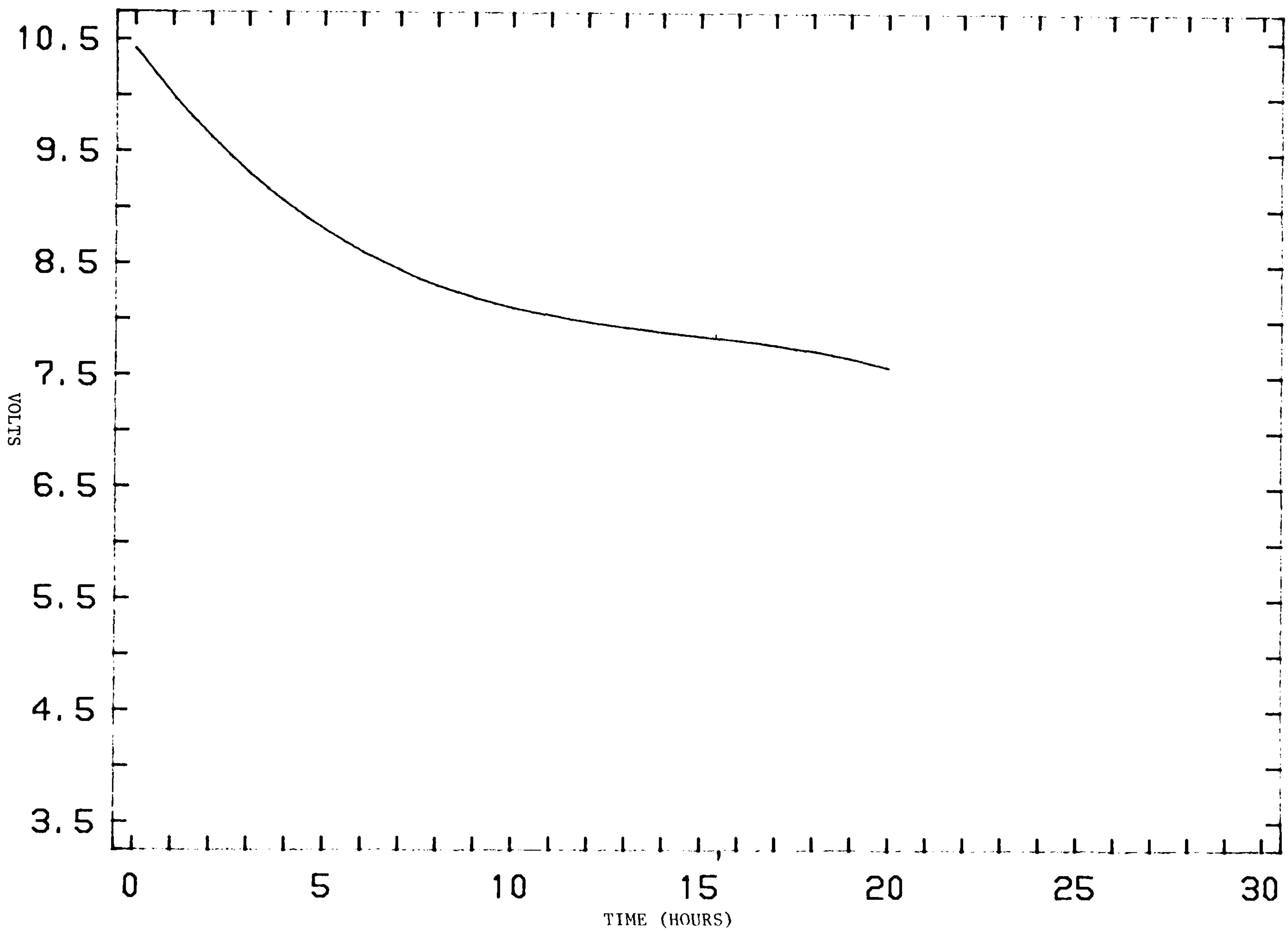


Figure 22. LOAD TEST VOLTAGE VS. TIME 40 DEG. F.

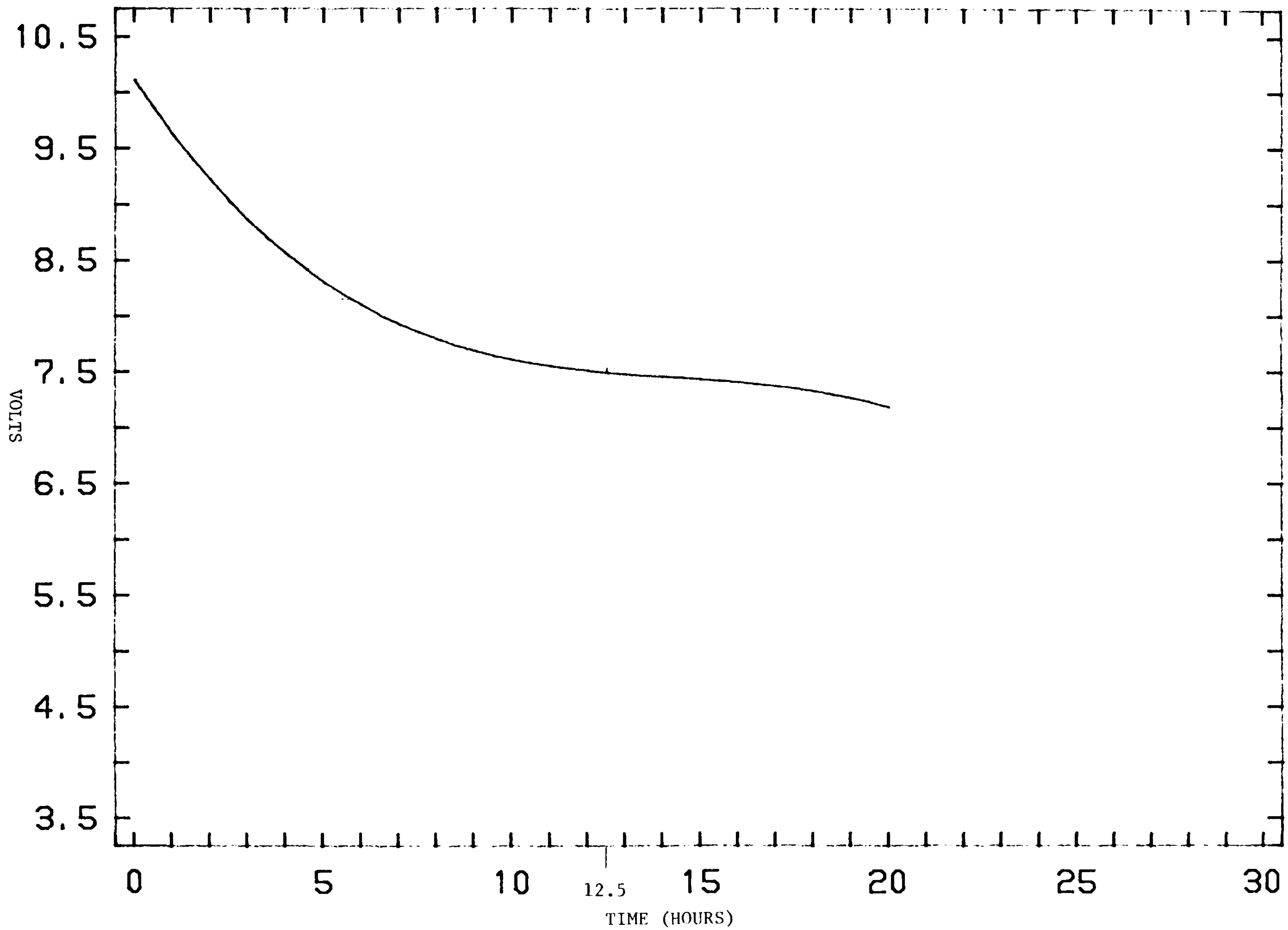
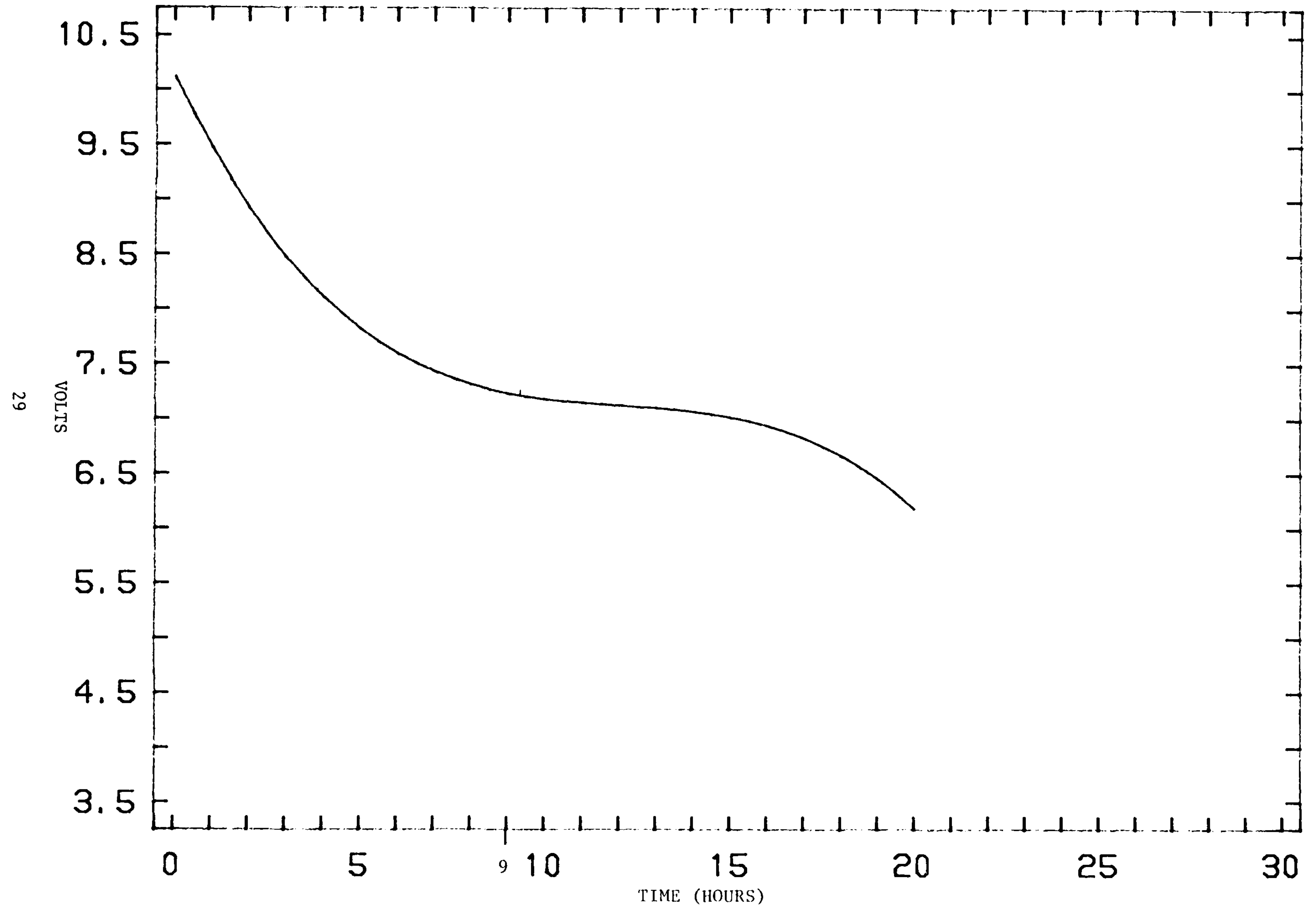


Figure 23. LOAD TEST VOLTAGE VS. TIME 30 DEG. F.



Appendix A. Figure 24 gives expected useful battery life for new batteries calculated from the load test voltage curves:

Water Temp °F	Hours
75	20
55	18
50	10
40	6
30	4

Figure 24. Expected Useful Battery Life of the MK 15 MOD 0 Batteries at Various Temperatures

C. Pre-Dive Load Test Procedures and Dive Planning. Figures 19 through 24 are the average of the load test curves minus one standard deviation at 30, 40, 50, 55, and 75°F. 8.2 volts is the point at which useful battery life ends. Before each dive, the battery should be load tested using a 12 ohm resistance applied for 1 second. The temperature of the battery at the time of the load test and the water temperature in which the dive will occur are used to determine the temperature/voltage offset. The temperature/voltage offset is added to the average voltage between the two sides of the battery to determine the corrected voltage of the battery at the operating temperature. Using the load test voltage vs time curve that is less than or equal to the water temperature of the anticipated dive, locate the corrected voltage on the vertical axis and the point on the curve corresponding to that voltage. The remaining useful battery life can be determined by locating the point on the horizontal axis corresponding to the previously determined point on the curve.

D. Optimum MK 15 UBA Battery. Three MK 15 batteries were tested, the new Seatronics battery, the currently used Biosystems battery, and the previously used Rexnord battery. The Seatronics unit exhibited at least 10% more life than the other types when run under identical conditions. This was expected due to the nature of the new "cram" cells contained within the Seatronics battery. Duracell claims a 15 to 20% increase in battery life for these cells over their standard AA manganese alkaline cells.

E. MK 15 UBA Solenoid. The currently used MK 15 6.0w solenoid is suitable for all present applications. The amount of power consumed by the solenoid is not a major part of the overall power consumption of the MK 15 UBA. Retrofit of the 6.0w solenoid with the new Rexnord 4.5w solenoid in all MK 15 UBAs is not warranted, however the new solenoid offers a suitable spare part replacement item to the 6.0w Solenoid whenever replacement of the current solenoid is required. A substantial increase in battery life will not be realized by installing the 4.5w replacement.

VI. CONCLUSIONS

A. Load Test. Because battery voltage measured under a no-load condition does not provide an accurate measurement of the batteries true state, a load tester should be acquired for the MK 15 UBA battery. The load tester should apply a 12 ohm resistance to each side of the battery pack for 1 second.

Battery duration times for a given load tested battery voltage are a function of the battery temperature at the time the load test is conducted and the water temperature of the anticipated dive. MK 15 UBA batteries are typically stored in refrigerators at user activities. It is important to know the refrigerator temperature in order to determine the temperature/voltage offset. When a battery is removed from the refrigerator, a minimum of 2 hours is required for the battery to reach ambient temperature.

Simplified battery load test procedures are provided in Appendix A.

B. Battery. The new Seatronics battery will provide a minimum of 10% more life than the currently used battery, and is recommended for use with the MK 15 UBA. The data provided in this report is based upon measurements on the Seatronics battery. If AA manganese alkaline battery packs are used which do not utilize the new Duracell "cram cell" technology, then duration data should be downgraded by 10%.

C. Solenoid. It is recommended that the 4.5w solenoid be provided as a spare part replacement item within the Navy stock system for the currently used 6.0w MK 15 UBA solenoid. Discussions with Rexnord, Inc. indicate that the 6.0w solenoid is no longer commercially available.

D. Battery Storage Life. Discussions with Duracell, Inc. indicate that the AA manganese alkaline battery can be stored at temperatures between 77° and 50°F, with a maximum relative humidity of 65%. These cells can be expected to retain 93% to 96% of their original capacity after 1 year of storage at 70°F. After 4 years at 70°F, approximately 80% of original capacity will be retained. Storage at temperatures above 77°F will accelerate loss of shelf life. Storage in a refrigerated environment will not increase shelf life, although it will not harm the cell.

APPENDIX A

SIMPLIFIED PREDIVE LOAD TEST PROCEDURES

- Determine the approximate temperature of the battery. If batteries are stored in a refrigerator, use the temperature of the refrigerator. Two hours are required for the battery to equalize with ambient temperature. Therefore if the battery is maintained at 75°F room temperature for at least 2 hours prior to the load test, a battery temperature of 75°F can be assumed.

- Determine the approximate water temperature in which the dive is to take place.

- Determine the temperature/voltage offset from Figure A1.

- Load test the battery using a MK 15 UBA battery load tester.

- If the voltage between the two sides varies more than 0.5 V, reject the battery.

- Record the average voltage from the two sides of the battery.

- Add the temperature/voltage offset to the average voltage to obtain corrected voltage.

  Average Battery Voltage + Temperature/Voltage Offset = Corrected Voltage.

- Using the curves provided in Figures A2 through A6 corresponding to the water temperature of the dive, locate the corrected voltage on the vertical axis.

- Locate the point corresponding to the corrected voltage on the curve.

- The remaining useful life of the battery for a particular point on the curve can be determined from the horizontal axis.

- Termination of each curve is the point at which useful battery life ends, 8.2 volts.

EXAMPLE:

A new MK 15 UBA battery is removed from a storage room at 70°F while performing a predive set up for a SDV mission in 35° water.

The temperature/voltage offset from Figure A1 is -1.2 V.

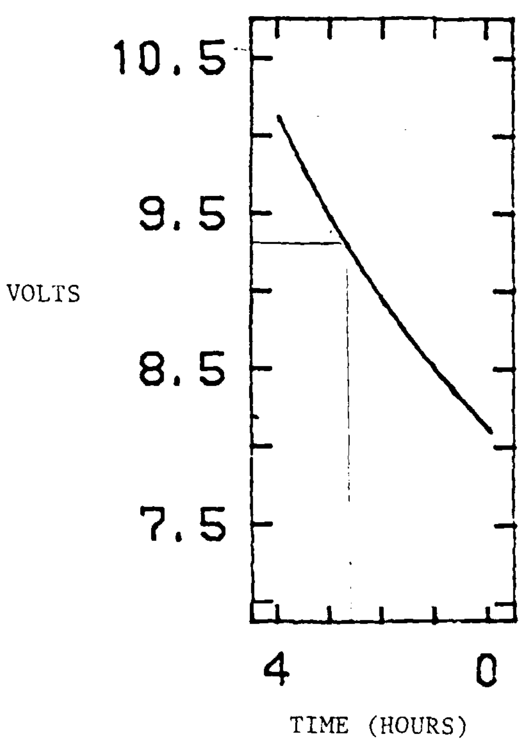
The battery load tested voltage is 10.5 V on each side.

The corrected voltage is load test voltage plus the temperature/voltage offset.

10.5 V + (-1.2 V) = 9.3V

Using the 30°F curve, locate the corrected voltage on the vertical axis. Locate the point on the curve that corresponds to the corrected voltage 9.3 V. To find the remaining useful life of the battery, find the point on the horizontal axis that corresponds to the point on the curve. This battery has approximately 2.5 hours of useful life remaining.

LOAD TEST VOLTAGE VS. TIME 30 DEG. F.



TEMPERATURE/VOLTAGE OFFSET TABLE

Battery Storage Temperature	water temperature				
	30	40	50	60	70
30	0	.3	.6	.9	1.2
40	-.3	0	.3	.6	.9
50	-.6	-.3	0	.3	.6
60	-.9	-.6	-.3	0	.3
70	-1.2	-.9	-.6	-.3	0

Figure A1. Temperature Voltage Offset Calculated from Figure 17 for Average Discharged Batteries

FIGURE A2. LOAD TEST VOLTAGE VS. TIME 75 DEG. F.

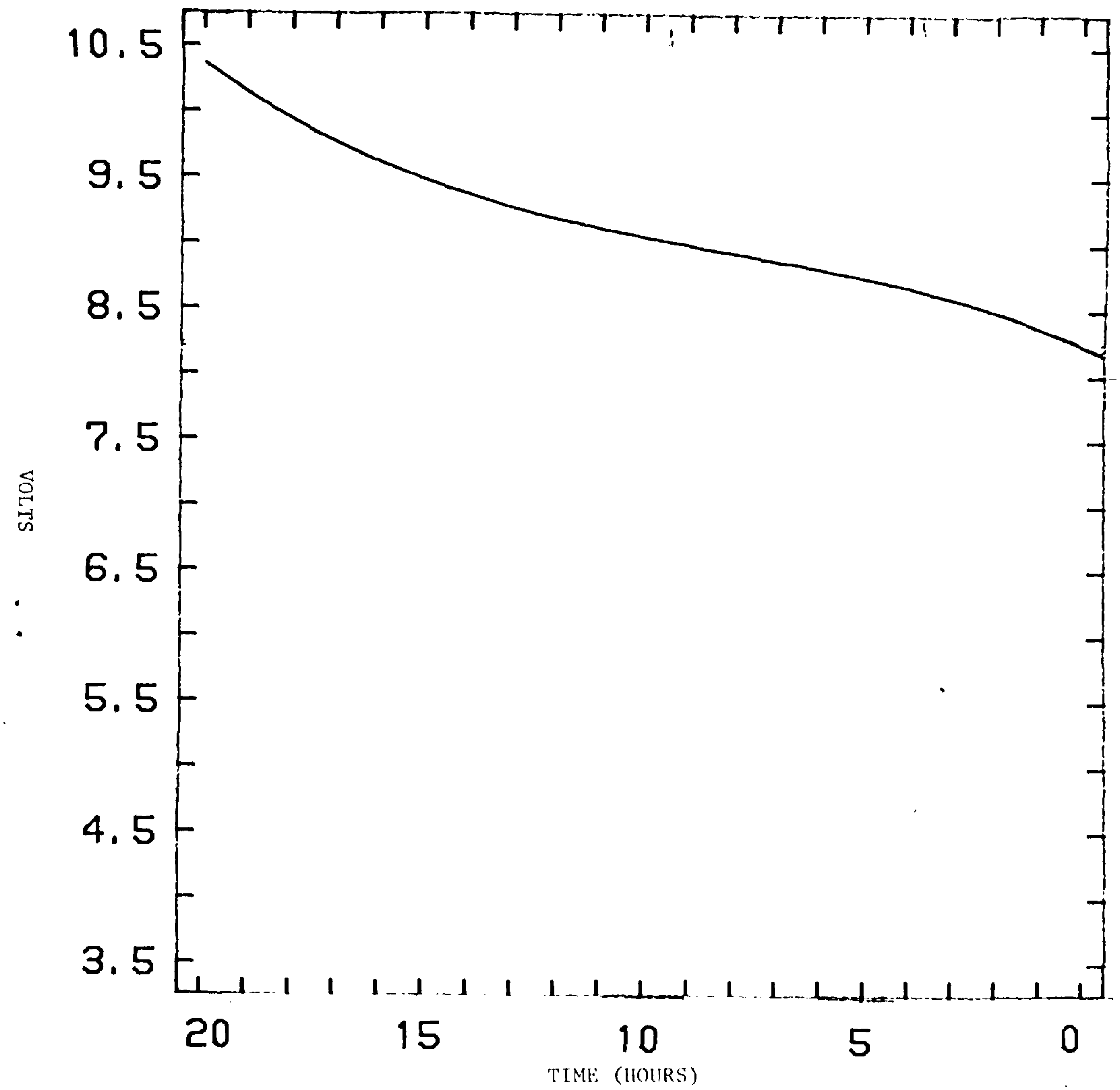


FIGURE A3. LOAD TEST VOLTAGE VS. TIME 55 DEG. F.

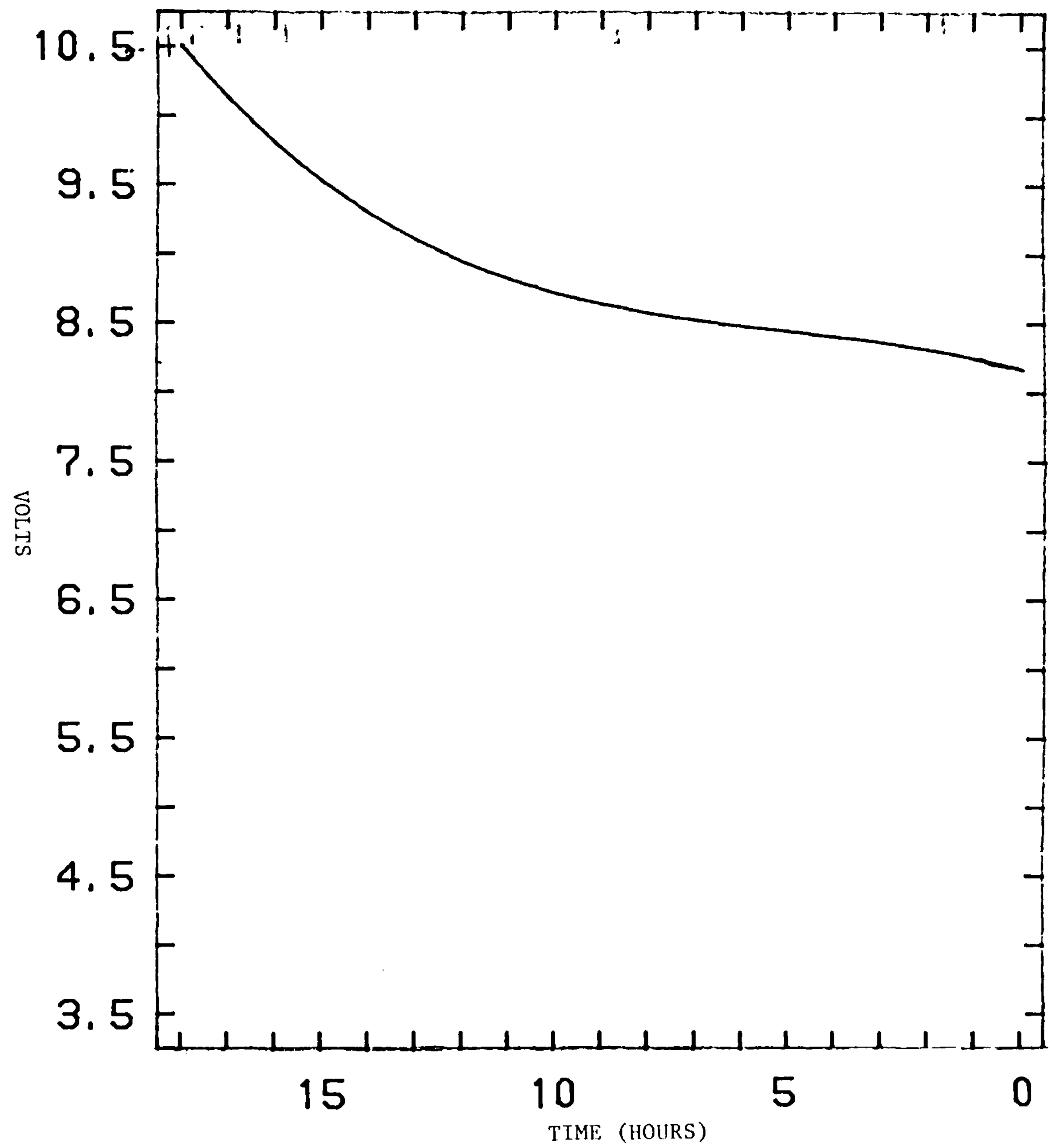


FIGURE A4. LOAD TEST VOLTAGE VS. TIME 50 DEG. F.

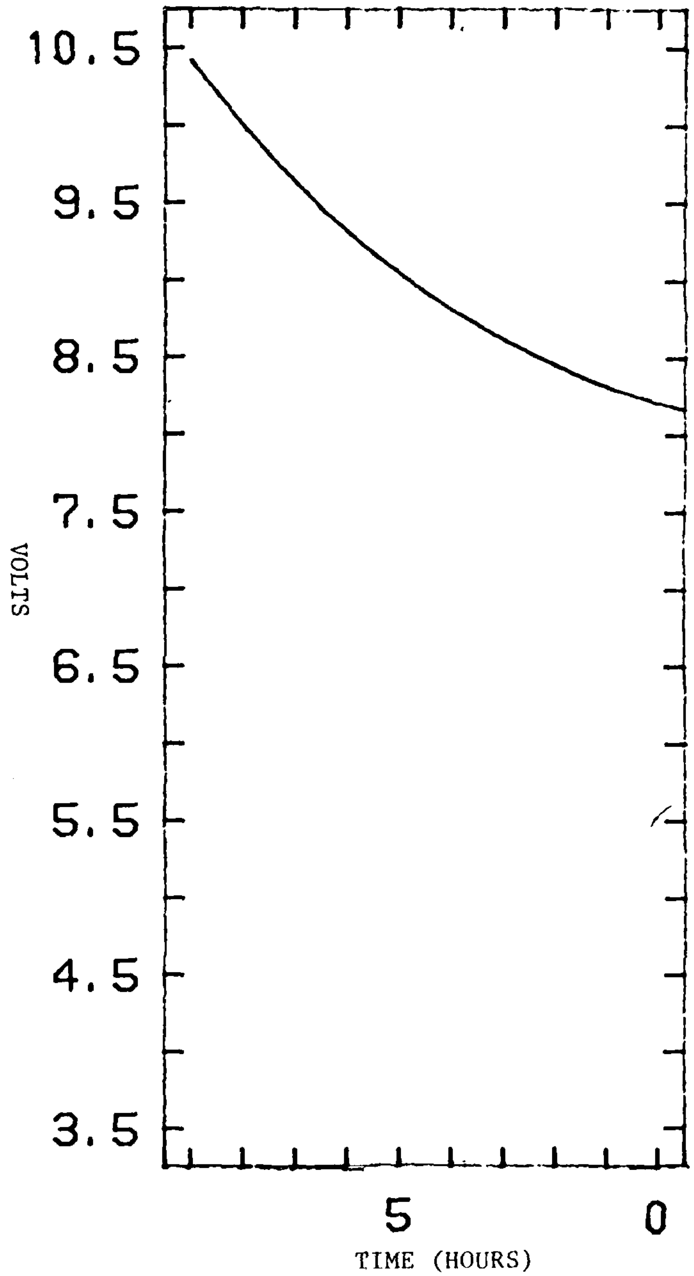


FIGURE A5. LOAD TEST VOLTAGE VS. TIME 40 DEG. F.

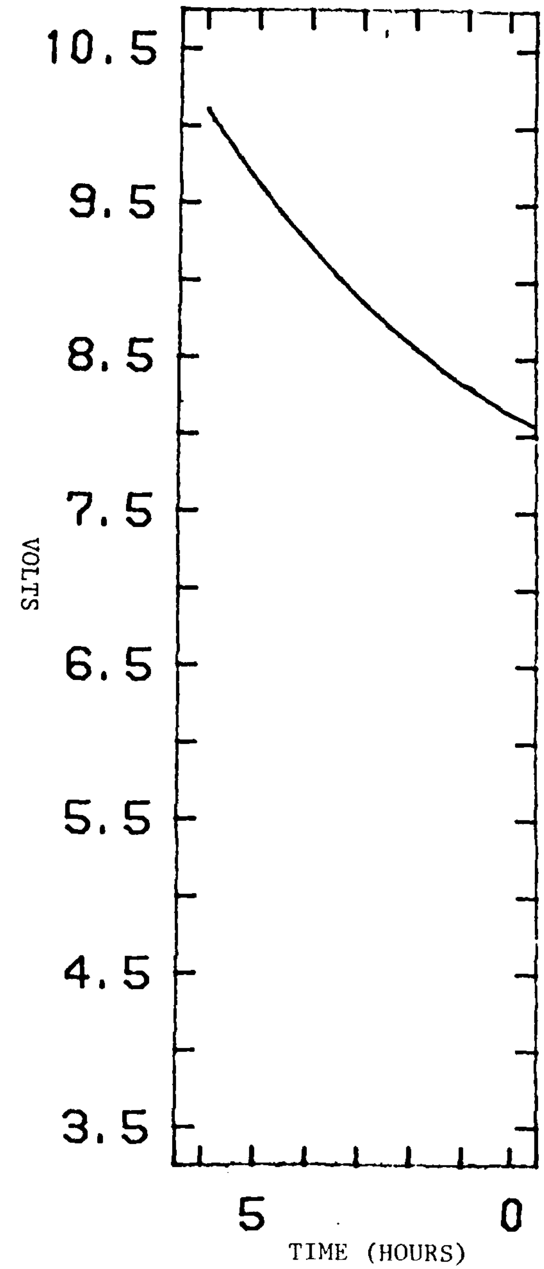
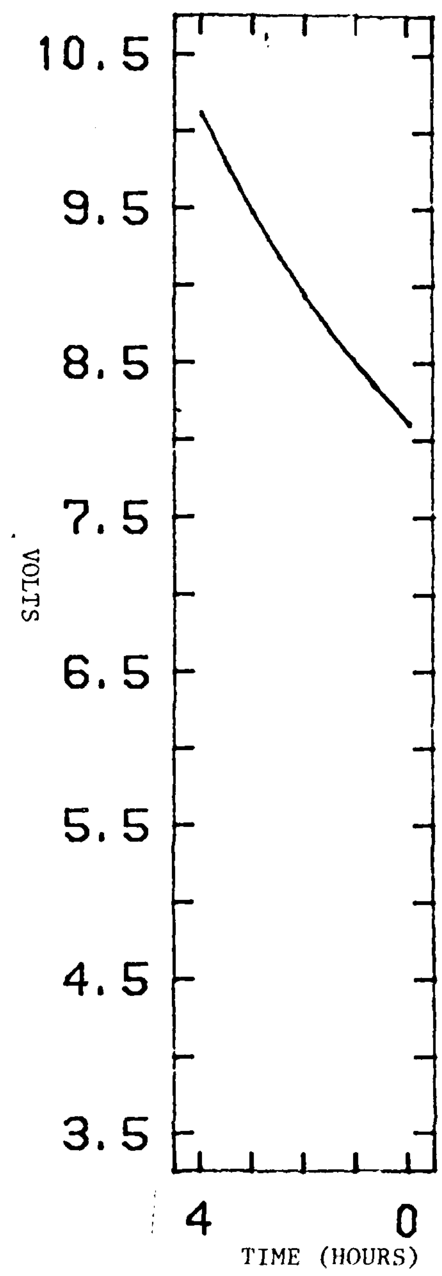


FIGURE A6. LOAD TEST VOLTAGE VS. TIME 30 DEG. F.



ANNEX B

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

IN REPLY REFER TO:

NAVY EXPERIMENTAL DIVING UNIT

STANDARD TEST PLAN

UNMANNED TEST AND EVALUATION OF THE MK 15 MOD 0 UBA
MANGANESE ALKALINE PRIMARY BATTERY

TEST PLAN NUMBER 86-20

NOVEMBER 1986

Submitted:

C.G. PRESSWOOD
LT, USN
SPECWAR Projects Officer

Reviewed:

R.T. MACHASICK
LCDR, USN
Operations/Projects Officer

Approved:

J.D.M. HAMILTON
CDR, USN
Commanding Officer

D.J. SCHMITT
GS-12
Technical Support Department
Head

J.C. DEVLIN
LCDR, USN
Executive Officer

DISTRIBUTION: Codes 00, 01, 01A, 02, 03, 031, 04, 07
Original to Technical Library

RECORD OF CHANGES

Except as provided for herein, changes will be made only on the authority of the Commanding Officer, NEDU. A dark vertical line in the left-hand margin indicates the coverage of change.

CHANGE NO.	AUTHORITY	INSERTION	SECTION	INITIAL

TABLE OF CONTENTS

	Page
Record of Changes	2
Table of Contents	3

SECTION:

		Page
1.	Introduction	4
2.	Personnel Requirements	5
3.	Test Parameters	5
4.	Instrumentation	5
5.	Test Procedure	6
6.	Program	7
7.	Safety Rules and Emergency Procedures	7
8.	Report Production	7

Reference

(a) NAVSEA Task 86-30

1. Introduction. Per reference (a), the purpose of this test is to conduct an evaluation of MK 15 MOD 0 UBA battery duration under various operational scenarios, including various diver work rates and temperatures. Particular emphasis will be placed on the effects of a cold water environment (45°F and below) and periods of exposure to sub-freezing temperatures during storage and surface intervals. The goal of testing is the establishment of a table which will reliably predict MK 15 MOD 0 battery life as a function of temperature and diver work rate.

The MK 15 MOD 0 UBA operations and maintenance instruction, NAVSEA 0994-CP-016-1010 sets the following guidelines concerning the functioning of the MK 15 manganese alkaline primary battery:

a. Voltage readings of 11.5 VDC or higher permit dives to 6 hours.

b. Voltage readings between 10.5 and 11.4 VDC limit dives to 2 hours.

c. Reduction of battery voltage during a dive below 9 VDC will cause the alarm light on the primary display to illuminate. Flashing will occur with each firing of the solenoid.

d. The MK 15 electrical system is designed to function for 2 to 6 hours after the alarm light is triggered, depending on water temperature and diver work rate.

Operational experience has indicated that cold water reduces battery life by an undetermined amount, yet the MK 15 technical manual does not address this problem. Additionally, the effect of cold air during surface intervals or prior to the dive may be severe.

Measurement of battery voltage under a no-load condition may not provide a good indication of a battery's true state. A better indication of a battery's true state is acquired through measurement of battery voltage under loading. Although NEDU has previously recommended the use of the Simpson model 379 battery tester in conjunction with the multimeters presently required by the MK 15 technical manual, a more in-depth study of the proper load conditions under which the MK 15 battery should be subjected during a load test needs to be conducted. This will also be the focus of the MK 15 battery evaluation discussed herein.

An improved Duracell battery may now be available for use with the MK 15 MOD 0 UBA. Additionally, a new Eveready battery assembled by Biosystems, Inc. has recently been introduced into the stock system. This evaluation will investigate the effectiveness of both of these batteries with the goal of recommending the most preferable battery for use with the MK 15 MOD 0 UBA.

2. Personnel Requirements. NCSC Code 3410 personnel will provide engineering support. Actual support personnel are listed as follows:

a. SPECWAR Projects Officer/Task Leader: LT C.G. Presswood.

b. SPECWAR Division MK 15 MOD 0 UBA Technician: HTC D.W. Laconte.

c. Test and Evaluation Division Technician as required to set up chamber operation and breathing machine (anticipate two individuals).

d. NCSC Engineering Support Project Leader: J.D. Dudinsky. Additional Support: M. Lippitt and E. Landstra.

3. Test Parameters. Battery testing will be conducted in three phases. Phase I will review the data provided by the manufacturer as to the battery characteristics at various temperatures including freezing, which should include the amount of battery regeneration with rewarming. This will be used to determine the battery's life expectancies under varying conditions. Should the manufacturers information prove to be incomplete or inadequate, voltage drop as a function of temperature will be evaluated using a thermocouple arrangement installed in a MK 15 MOD 0 battery which is exposed to various temperatures.

Phase II testing will evaluate battery drain at various oxygen consumption rates (solenoid firing rates). A MK 15 MOD 0 UBA will be connected to a breathing machine at various depths and various oxygen consumption rates will be simulated using the EDF oxygen consumption simulator. A current shunt will be inserted into both hot leads coming from the battery. This will allow the total current drawn from the battery to be determined for the functioning of the UBA and when the solenoid fires. The voltage drop across each shunt will be recorded by the HP 1000 computer providing an effective means of computing power drain, which is a function of current vs. time. The number of solenoid activations during this time will be noted.

Phase III will integrate the manufacturers specifications (and NEDU verification testing if required) and the amount of power required by the UBA under various conditions into a graph of expected battery duration under various work rates, depth and temperature. Representatives from Duracell, Inc. have indicated that battery life should be considered terminated when cell voltage under load drops below 7.2 volts.

Verification testing will include an evaluation of actual battery life at various temperatures and power consumptions. This evaluation will take place in a constant temperature bath. A load simulator will be used to provide power consumption.

4. Instrumentation. The following equipment will be used to conduct the test.

a. Phase I: provided by the manufacturer.

b. Phase II (EDF) -

(1) O_2 consumption simulator.

(2) Test UBAs.

(3) Beckman 755 paramagnetic analyzer for monitoring O_2 in the divers inhaled gas.

(4) Breathing machine.

(5) HP 1000 computer terminal to monitor battery voltage over time.

(6) Chamber "C" test arc and chamber.

(7) Test shunt compatible with MK 15 battery interconnecting cable.

(8) Multimeter to monitor voltage and provide data output for number of solenoid activations which will be recorded on a counter.

c. Phase III

(1) HP 1000 computer for data analysis.

(2) Constant temperature bath.

(3) Load simulator.

(4) Multimeter.

(5) Timekeeping device.

5. <u>Test Procedure</u>

a. Phase I: as per manufacturer.

b. Phase II

(1) Insure UBA is set to factory specifications and is working properly.

(2) Chamber will be pressurized to 0, 50, 100, 150 FSW.

(3) Calibrate transducers and Beckman 755 analyzer.

(4) Attach shunt to battery interconnecting cable, immerse UBA in test arc.

(5) Start breathing machine and O_2 consumption system. Various O_2 consumption rates: .35, 1.0, 1.5, 2.0, and 2.5 l/m for the various depths.

(6) Record voltage drop across current shunt vs. time using the HP 1000 computer. Multimeter/counter will indicate the number of solenoid firings. Volts divided by resistance will indicate current. This data will establish the power drains at different temperatures and depths.

c. Phase III: correlation of battery characteristics to power requirements to determine expected battery life.

6. Program

a. Phase I testing requires no NEDU personnel.

b. Phase II testing is anticipated to require 15 working days in the EDF, using 3 personnel.

c. Phase III testing is anticipated to require 20 working days, using 2 personnel.

7. Safety Rules and Emergency Procedures. As specified by the EDF Operations Manual.

8. Report Production. An NEDU Report and letter of recommendation, drafted by the SPECWAR Projects Officer in conjunction with NCSC Code 3410 personnel, will be forwarded to NAVSEA 00C upon the conclusion of testing and data reduction.